

The design of a modelling framework to simulate the local
food system of a rural community in Zimbabwe.

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Abstract

In sub-Saharan Africa, forecasts of regional or national scale malnutrition are prepared using a variety of 'Early Warning Systems', based upon supply-side data such as crop forecasts and satellite images of vegetation growth. Three agencies are developing more localised targeting systems using historical indicators to prepare 'vulnerability assessments' and so predict malnutrition at sub-national scales. This work argues that an alternative approach of short-term simulations of local food systems, may offer benefits.

The design of a modelling framework to carry out such a simulation, for a rural community of Zimbabwe, is presented together with the associated data requirements. The thesis reviews the current literature concerning food security, particularly the monitoring of food shortages, the targeting of emergency food aid and the economic and nutritional perspectives of the causes of malnutrition. The extent of spatial and temporal variability amongst households is analysed from primary survey data. The design implications of this variability and of the hierarchical structure of the rural socio-economy and grain trading are discussed. Two versions of the modelling framework are reported, the first using systems dynamic modelling and the second using expert systems simulation techniques.

The first framework uses the UNICEF diagram of the 'malnutrition-infection complex' to develop the central component of the simulation. The second framework combines a 'rulebase' of household and community behaviour with rainfall and health statistics to effect changes upon a database of households, data for which are extrapolated from the primary survey and secondary data obtained. The effectiveness of the framework and the direction of future work thereon are discussed.

Declaration of originality

I hereby declare that this thesis has been composed by me and that all the work presented in this thesis is my own, unless specifically stated otherwise.

Stephen W. Gundry

14 March 2000

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Note concerning publication, reporting and presentation of thesis material

The following published conference papers were based on work presented in this thesis:

Gundry, S.W., Wright, J.A., Ferro-Luzzi, A. (1997): 'Simulating the food and nutrition system in rural Zimbabwe to support targetting of emergency aid.' *Paper presented at ModSim 97, the International Congress on Modelling and Simulation, Hobart, Tasmania. 8-11 December 1997. Published in the proceedings: McDonald A.D., McAleer M (eds), ISBN 0-86422-827-9. The Modelling and Simulation Society of Australia, 1997. Vol 3, pp1018-1022.*

Gundry, S.W., Wright, J.A. and Ferro-Luzzi, A. (1998) 'The use of a rule-base to simulate the food and nutrition system in rural Zimbabwe.' *Paper presented at the 4th World Congress on Expert Systems – Application of Advanced Information Technologies, ITESM, Mexico City, Mexico, 16-20 March 1998. Published in the proceedings: Cantu F., Soto R., Liebowitz J. and Sucar E. (eds) by Cognizant Communications Corporation, New York, U.S.A. March 1998, Vol 1, pp301-308.*

Gundry, S.W., Wright, J.A., Austin, E. and Worrall, E.J. (1999) 'Populating a Simulation Model of the Food System in Zimbabwe with Representative Household Data' *Paper presented at ModSim 99, the International Congress on Modelling and Simulation, University of Waikato, New Zealand. 6-9 December 1999. Published in the proceedings: Oxley, L., Scrimgeour, F. and McAleer, M. (eds), ISBN 0-86422-949-6. The Modelling and Simulation Society of Australia and New Zealand Inc., 1999. Vol 2, pp343-348.*

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workshop: *Diversity of Approaches to Household Food Security*, 2-3 February 1995, pp 11.

Gundry, S.W. and Ferro-Luzzi, A. (1996): 'An integrated model of the food system in a region of Zimbabwe'. *Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Scientific progress report to DGXII of the European Commission, for the period 1 February 1995 to 31 January 1996*, pp 193.

Gundry, S.W., Ferro-Luzzi, A., Mudimu, G., Vaze, P., Wright, J.A. (1996): 'Analysis of the food and nutrition system in Zimbabwe: a multi-disciplinary research project to model the interactions between income, agricultural production and health at household and community level.' *Paper presented at the Development Studies Association 1996 Annual Conference, University of Reading 18-20 September 1996*, pp 15.

Gundry, S.W., Ferro-Luzzi, A. and Wright J.W. (1997): 'An integrated model of the food system in a region of Zimbabwe'. *Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Scientific progress report to DGXII of the European Commission, for the period 1 February 1996 to 31 January 1997*, pp 156.

Gundry, S.W., Wright, J. and Vaze, P: (1997): 'An integrated model of the food system in a region of Zimbabwe'. *Oral presentation and poster paper. XXIIIth International Conference of Agricultural Economists, Sacramento, California 10-16 August 1997*.

Gundry, S.W., Wright, J. and Ferro-Luzzi, A. (2000): 'An integrated model of the food system in a region of Zimbabwe'. *Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Final report to DGXII of the European Commission*.

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In relation to each chapter of the thesis, I would like to acknowledge the following contributions:

Chapter 1 – parts are drawn from Gundry and Ferro-Luzzi (1994), a technical report to which others on the collaborative project contributed. As a result, some small sections of the text may be attributable to unnamed staff from the project.

Chapter 2 – some elements of the review of the 'malnutrition-infection' complex are drawn from the latter technical report and may be attributable to others.

Chapter 3 – the detailed design of the survey was carried out by staff of the research project. The sample frame was selected with assistance from Dr.B.P. Goel, Senior Agricultural Statistician in the FAO/SADC Early Warning System office in Harare. Various results from the analysis of the primary survey are summarised in this chapter and the text of this summary is taken from the report Gundry and Ferro-Luzzi (1996), to which others contributed.

Chapter 4 – the secondary data was collected and collated by staff of the collaborative research project. A summary catalogue of these data was provided to me by Dr.

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Chapter 5 – the subsidiary diagrams to Figure 5.1, enclosed in Appendix IV, were taken from Gundry and Ferro-Luzzi (1994) and were a joint development of several colleagues, in particular, Dr. Ann Conroy. Although the systems dynamic framework was designed and programmed by me, later versions included contributions from other project staff. Thanks are due to Dr. Robert Muetzelfeldt for his original suggestion of the 'four box' method of classifying healthy, sick, and malnourished individuals.

Chapter 6 – although these design considerations are essentially my own, Dr Vaze's PhD thesis provided valuable insight into the economic theory underlying grain trading. Similarly, Dr Wright's understandings of spatial analysis of various data helped my appreciation of the issues relating to the hierarchical structure that resulted.

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Chapter 8 – wholly my own!

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1 Introduction

1.1 Purpose

This introductory chapter sets out the objective of the work and provides a summary of the principal topics: food security, malnutrition and the methods used for forecasting these in southern Africa. The contents of the remaining chapters are summarised.

1.2 Objectives and hypothesis

The objective of the work is: *'To design a framework that can be used to build simulation models of the local food system to forecast spatial and temporal variability in nutritional status of inhabitants of a rural community in Zimbabwe'*.

The purpose of such simulation models is to support the targeting of food aid and other supplies. Potentially, the models can be extended over multiple seasons to inform rural development policy by analysing the comparative effectiveness of interventions. The users of such models are personnel from government (local and national), international agencies and Non-Governmental Organisations (N.G.O.s) concerned with aid and rural development.

Over ten years ago, Sahn (1989) wrote (p. 3): 'Food security, at the household level, is defined as adequate access to enough food to supply the energy needed for all family members to live healthy, active, and productive lives. Country-level aggregate data obscure the fact that even though a country may achieve adequate and relatively stable levels of food supply and prices, there may be great regional and local inequality and seasonal disparities in the distribution of consumption. For example, within a given town or village, only part of the population may face a seasonal shortage of food or display marked deficiencies in its levels of food intake.' Many studies have been undertaken to measure the impacts of seasonal food shortages upon communities and to identify the modulating factors at household, community and national level.

The findings from such studies suggest that the outcome variable, the nutritional status of the studied population cohort, is weakly correlated with numerous factors that interact with varying significance depending on location and time of year. This suggests that the food system at local level should be viewed as a dynamic system, exhibiting spatial and temporal variability, with complex causality.

This complexity has implications for targeting emergency aid. Currently, governments, non-governmental organisations (N.G.O.s) and aid agencies use various data to provide 'indicators' of population cohorts in need e.g. food availability, household income and morbidity statistics. These single variables or weighted aggregates may not identify all of those most in need and may falsely identify some of those not in need. Furthermore, indicators must by their nature offer a historical perspective. Although some are regarded as 'predictive indicators' (e.g. satellite images of crop growth processed to estimate harvest yields, grain market trend data), the prediction is usually limited to an extrapolation of a single factor, rather than an analysis of the effect upon the food system as a whole.

It is suggested that there is a need for an increased understanding of the food system, to complement the substantial body of findings relating to individual components thereof. It is hypothesised that: 'Nutritional, physiological and micro-economic analyses of household and community resources (human, economic and environmental) can be inter-related within a modelling framework to coherently represent the processes underlying the local food system'.

Ideally, a representation of the food system should be developed in the form of an extensible modelling framework that would allow apparently disparate research findings to be incorporated as sub-models on a consistent and commensurable basis. The framework should allow explicit recognition of spatial and temporal variability and provide appropriate outputs to enable calibration and validation of the sub-models. This work is concerned with the design of such a representation. Two modelling frameworks are developed using a systems dynamic method and an expert system simulation and their relative merits discussed.

The work is related to a collaborative research project, funded by the European Union, the proposal for which was written by the author. A copy of the technical annex to the contract for the project is enclosed in Appendix I. The research project concerned the development and implementation of a simulation model of the changes occurring in the nutritional status of members of subsistence farming households, within the Buhera District of Zimbabwe, during an agricultural season. This district lies some 200 km. to the south east of the capital Harare. It straddles three agro-ecological zones: in the north, soil and rainfall are suitable for arable farming, whereas in the south soils are poorer and droughts frequent. The district is approximately 6,500 square kilometres in extent, with a population in 1992 of 203,739 (Government of Zimbabwe, 1994).

Throughout the collaborative research project, the author co-ordinated the scientific research. Various parts of the project, in particular the nutritional, physiological and micro-economic analyses, the resultant sub-models and their validation were undertaken by research assistants and colleagues at partner institutions. The author was primarily responsible for the overall design of the modelling framework and the procedures that inter-relate the different sub-models. It is these topics that are addressed herein.

With this in mind, the following are presented as the detailed objectives of this thesis:

1. To establish that methodologies for nutritional, physiological and micro-economic analyses of subsistence farming communities are well documented or can be developed and are suitable for inter-related use (chapter 2).
2. To obtain, either by field survey or from secondary sources, sufficient data to characterise adequately household and community resources and analyse the effects of external factors (chapters 3 and 4).
3. To develop methods for inter-relating the analyses, within a modelling framework, to support the coherent representation of the processes underlying the food system (chapters 5 and 6).

4. To provide a modelling framework that will enable users to represent household and community resources and the short-term external factors (chapter 7).
5. To include, within the modelling framework, suitable methods of providing output data about changes in nutritional status, which are sufficient for comparison with independently derived data to confirm or otherwise the coherent representation of the processes (chapters 6 and 7).

It is not the objective of this work to design a modelling framework that can be applied in all areas (urban and rural) of Zimbabwe or in other countries. The design is based on the rural food system operating in the study area of Zimbabwe. It cannot be replicated or easily adapted to other areas where differences exist in the basic components of the food system. For example, urban areas will exhibit quite different income sources, food marketing channels and consumption patterns. Urban health services will also be markedly different. Even in other rural areas of Zimbabwe, the farming activities may differ substantially or different tribal customs may produce fundamentally different social structures. For rural areas of other countries, similarities in the food system at the local level may well exist, but differences in national food marketing systems will dictate the large-scale movement of staples between areas. However, to the extent that the study area (the Buhera District) is similar to other rural subsistence farming areas within Zimbabwe, the design should be modifiable and transferable for use therein.

1.3 Food security, sufficiency and malnutrition

Before introducing the background to food security in Zimbabwe, explanation of three important concepts is required:

- **Food security** - Sahn's definition of food security (as in 1.2 above) is 'Food security, at the household level, is defined as adequate *access* to enough food to supply the energy needed for all family members to live healthy, active, and productive lives.' The italicised emphasis on '*access*' follows Sen's (1981) work, where he used the records from the 1943 famine in Bengal to

demonstrate that adequate food supply alone did not produce food security. He showed that people needed to have the necessary means of access to food, brought about by their ability to acquire food either by production, purchase/trade or gift. Sen described these as people's 'entitlements'.

- **Sufficiency** – What is 'enough food' in the definition above? It is generally accepted that 2,500 kilocalories per day for an adult man, 2,200 kilocalories for a woman and 1,500 kilocalories for a child are sufficient for 'an active, healthy life' (World Bank 1986). (N.B. Data published by international agencies usually provide inter-country comparison of *national* self-sufficiency, a measure of total annual national food production relative to the aggregate annual calorific requirements of the population.) Although these requirements of kilocalories are the international guidelines, it is accepted that three point values mask wide variation by age, sex, occupation and geographical location. Furthermore, for rural populations engaged in outdoor activities, the requirements will vary during the year with ambient temperature and with the seasonal workload. Payne and Lipton (1994) show that nutritional requirement is a function of age, health, size, workload, environment and behaviour. A recent report 'F.A.O./W.H.O. expert consultation on carbohydrates in human nutrition' (Food and Agriculture Organisation of the United Nations, 1997b) provides data (p.58) for calorific intake, disaggregated by two groups: developed and developing countries. For 1994, developed countries were shown on average to consume 3,206 kilocalories per person per day (kcal ppd) of which 1,598 kcal ppd were carbohydrates, whereas developing countries consumed 2,573 kcal ppd of which 1,751 kcal ppd were derived from carbohydrates.
- **Malnutrition** – Following from the definition of sufficiency, malnutrition can be considered to be the physiological state arising from an insufficient intake of food. However, the United Nations Administrative Committee on Co-ordination, Sub-Committee on Nutrition (A.C.C./S.C.N.) has recognised that qualitative issues may also be relevant to determining sufficiency (A.C.C./S.C.N. 1991). Thus the A.C.C./S.C.N. now refers to quantitative insufficiency as 'Protein Energy Malnutrition' (A.C.C./S.C.N., 1997) to differentiate from 'Micronutrient Malnutrition' where qualitative issues prevail.

Notice that 'intake of food' is used rather than 'food' alone. This emphasises the importance of disease on an individual's ability to take up the ingested food and is of particular relevance to child malnutrition. Malnutrition will also have a time dimension. Where malnutrition occurs for a short period of time it is referred to as 'acute'. Where malnutrition is persistent, but not necessarily constant (e.g. occurring seasonally, each year) it is 'chronic' and will effect children's growth. How are these different types of malnutrition to be distinguished in the physiology of an individual? How is the increasing severity of malnutrition to be measured? Micronutrient malnutrition is usually identified by reference to the physiological impairment caused (e.g. iodine deficiency – goitre; iron deficiency – anaemia). For protein energy malnutrition, nutritionists are in broad agreement that indicators can be derived from anthropometry ('the measuring of the body') of children and adults to describe adequately type (acute or chronic) and severity (relative to international standards). For adults, mass in kilograms divided height in metres squared ('Body Mass Index') is the principal indicator. For children, acute malnutrition presents as 'wasting', recognised anthropometrically as a shortfall in weight for a given height ('Weight-for-Height'). Chronic malnutrition in children presents as 'stunting', recognised anthropometrically as a shortfall in height for a given age ('Height-for-Age'). Statistics from international reference populations are available for both the adults' and children's measures to scale any studied group.

1.4 Malnutrition in sub-Saharan Africa

In sub-Saharan Africa, malnutrition has remained an intractable problem for policy makers within governments, international agencies and donors. For many countries, the paradox of national food self-sufficiency and localised malnutrition is symptomatic of underlying, long-term economic and social problems. A variety of indicators - declining agricultural production per head, low food exports or food imports, high food prices, rural to urban migration - suggest poor economic performance in rural areas. Inequality of land distribution has lead to a tradition of migrant male labour in the poorer households, where yields will not sustain the food

requirement of all family members. Between 1961 and 1988, population growth at 2.3 percent exceeded annual food production growth of 2.0 percent (World Bank, 1989). At the same time, small farmers were encouraged to switch from staple food crops to cash crops, with government schemes to improve incentives for cash crops such as provision of inputs and access to the marketing system. The poorest have been reluctant to realise the incentives. Smallholders are unable to spread the risk associated with high value cash crops, especially the variability in price (de Janvry et al., 1991). In Zimbabwe, Jayne (1994) notes that the high opportunity cost of these crops may be greater than the sale price when prices of staples are high - small farmers have to purchase staple crops which otherwise would have been grown on land under cash crops.

Sen's (1981) concept of 'entitlements' for a subsistence farming household has shown that an understanding is required not only of the food supplies available, but also of the ability to procure such supplies, by taking account of other sources of income, access to credit for purchase of inputs and accumulated non-food assets. It is now accepted that 'food access' is a more appropriate term to describe this comprehensive approach than 'food supply'.

The use of the term 'food access' however implies a further consideration: that of the physical or spatial accessibility of the household to the markets in which the necessary supplies (of both food and inputs for home produced supply) can be obtained and the household's production (cash crops and surplus staples) can be sold to provide income. Appropriate measures of accessibility will include not only simple distance calculations, but also topography, roads and transport services. The relative quality of markets versus their accessibility will also need to be considered. Many African governments, at the behest of international agencies, have invested heavily in rural infrastructure to improve grain marketing systems, agricultural extension and veterinary support, as well as health, education and social services. Whilst substantial progress has been made in the provision of such services, in many southern African countries this rural infrastructure remains weak.

1.5 Food security in Zimbabwe

Until recently, Zimbabwe was regarded as being self-sufficient in food, with national production, expressed on a per capita basis, exceeding World Health Organisation (W.H.O.) recommended daily requirements. White maize is the principal staple, with millet and sorghum being important drought resistant subsistence crops. Although aggregate national food supplies are adequate, significant levels of malnutrition exist, particularly in rural areas, with both inter and intra-seasonal variability being evident (Ferro-Luzzi et al., 1992). Jayne and Chisvo (1991) have referred to this as Zimbabwe's 'food insecurity paradox'.

The structure of agriculture in modern Zimbabwe reflects its colonial past. It now comprises four main sectors: a large-scale commercial sector; a small-scale commercial sector; resettlement areas and the communal lands. The table below summarises the relative land distribution and the number of farms in each sector:

Sector	Land in sector ('000s Ha)	Number of farms ('000s)
Large scale commercial	11,212	5
Small scale commercial	1,237	9
Resettlement areas	3,290	51
Communal lands	16,355	(approx.) 1,000
Parks, state land etc	5,488	0
Total	37,582	1,065

Table 1.1 Land distribution and farm numbers for each sector of the Zimbabwean agricultural industry (Roth, 1990).

Land in Zimbabwe is classified by agro-ecological zone and the map below shows the national distribution of this zoning:

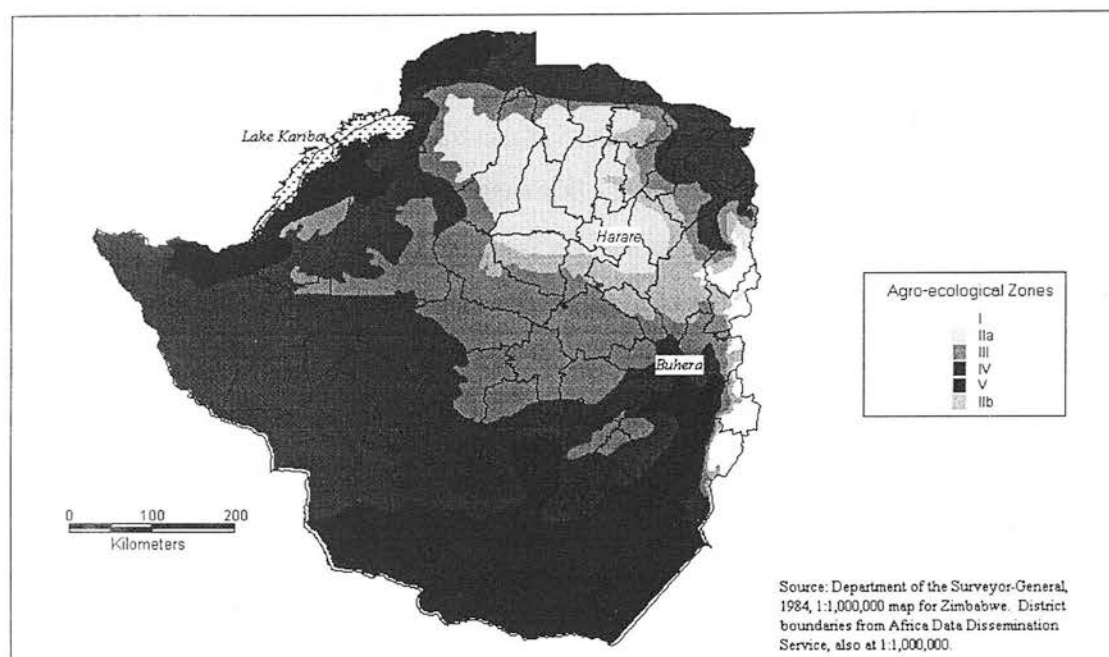


Figure 1.1 Map of the agro-ecological zones of Zimbabwe (Government of Zimbabwe, 1984).

The large-scale commercial sector is located on the more fertile lands (agro-ecological zone IIa) to the north of the capital, Harare. It comprises the farms mainly owned by white Zimbabweans and is currently the focus of the Government of Zimbabwe's programme of land redistribution. Black Zimbabweans mainly own the farms in the small-scale commercial sector and resettlement areas, located in agro-ecological zones IIb and III. In the Communal Lands (formerly the Tribal Trust Lands), which are located in agro-ecological zones IV and V, the majority of farming households are grain-deficit in most years (Corbett, 1994). In many of these households, one or more of the adult men will work in the cities or further afield for part of the year. Income is remitted to the household periodically to supplement subsistence food production by purchased staples from local market sources.

Since independence, the government has made substantial enhancements to the infrastructure in the poorer rural areas by improving agricultural extension services, roads, transport, water supplies, sanitation and healthcare. These changes have been reflected in improved mortality and morbidity statistics; nonetheless, malnutrition rates remain high, particularly in the semi-arid and arid lands to the south and west of the country. An analysis of the 1994 Demographic and Health Survey for Zimbabwe

(Macro International Inc. et al., 1996) concluded that 28 percent of all deaths among children under five years of age were related to malnutrition, the majority of which was moderate rather than severe. The authors suggest therefore that nutrition programmes should target both moderate and severe malnutrition, as this will have a significant impact upon child mortality. This has an important implication for the work herein: implemented simulation models should forecast not only the onset of a famine or outbreaks of severe malnutrition, but should also forecast the more pervasive moderate malnutrition that contributes to the high morbidity and mortality of children under five years of age.

1.6 Crop forecasting, 'early warning' and targeting systems

For agriculturally based economies, with substantial subsistence farming, food supply is predominated by the harvest performance and correlated to environmental risks e.g. fluctuations in rainfall quantity and seasonal distribution, incidence of crop disease or pestilence. The forecasting of harvest performance has long been the responsibility of government agricultural departments throughout the world, with forecasts in developing countries being used to estimate food supply and hence shortages and potential famines (Staatz et al., 1990). Crop forecasting systems - either by traditional methods of terrestrial based observation via the agricultural extension services or by remote sensing from satellite - rely on the coupling of environmental data to estimates of planted area by crop and farming system, to produce estimates of gross yield from mid-season onwards.

Zimbabwe, in common with many other developing countries, employs a variety of information systems to monitor growth of the principal staples during the agricultural season. These systems can be considered under three headings (with much overlap):

- **Crop forecasting** – forecasts produced usually by the national ministry of agriculture, based on regular survey reports from the extension service, of the state of growing crops and expected yields. In Zimbabwe, these are four-weekly and cover staples and cash crops.

- **‘Early warning’** – where crop forecasts are enhanced with data about stock levels, they are then often styled ‘early warning systems’, as in the case of Zimbabwe’s National Early Warning System. Forecasts of staple crop harvests can be produced either by survey (as above) or by interpretation of wide area satellite imagery, based on the different infrared reflectance values of cultivated, uncultivated and bare land. These are augmented by estimates of stocks held by households, traders and the parastatal grain marketing boards to provide early warning of shortfalls in food availability. Technical support for such systems is usually provided by the Food and Agriculture Organisation of the United Nations (F.A.O.) and operated at regional scale. In southern Africa, the regional system is a joint venture between F.A.O. and the Southern African Development Community (S.A.D.C.).
- **Targeting** – forecasts are used to identify those areas likely to suffer shortages in food availability through production deficits and additional socio-economic data are used to target population groups most at risk of food insecurity.

Such systems are the cornerstone of the ‘supply side’ approaches to nutritional security and have performed well in predicting famines on a wide area basis. As an example, the success of the countries within S.A.D.C. in responding to the 1992 drought in the region was partially a result of the quality of forecasts produced by the combination of national early warning systems (terrestrially based) and the S.A.D.C./F.A.O. Regional Early Warning System (remote sensing) based in Harare. However, the scale at which such systems are operated, particularly those reliant upon remote sensing, is often too broad to identify localised food supply problems. Thus, whilst potential major famines are forecast adequately, smaller outbreaks of localised malnutrition are not easily identified, being lost against the coarsely aggregated data. Several authors (Ferro-Luzzi et al., 1994; Longhurst, 1986) have also noted intra-seasonal and inter-seasonal variation in rates of malnutrition. For semi-arid areas, with inconsistent incidence and quantity of rainfall, this spatial and temporal variability in malnutrition is observed within small communities.

In summary, aggregate supply side statistics are not sufficient indicators of nutritional security for three main reasons: (1) aggregation ignores the uneven spatial distribution

of production and the variability of food demand and supply in the year; (2) supply side statistics do not represent households' ability to purchase the available food supplies; and (3) the effect of health upon nutritional status is ignored.

1.7 The 'malnutrition-infection' complex

Epidemiologists have recognised that the incidence levels of the principal children's diseases in sub-Saharan Africa (measles, tuberculosis, malaria, diarrhoea, respiratory infections and bilharzia) are known to have a pronounced seasonal variability (Government of Zimbabwe, 1988; Kambarami et al., 1991; Aron and May, 1996). Spatial variability is also observed in the localised outbreaks of disease.

The mechanisms by which the temporal and spatial variabilities of food shortage and disease combine to create 'hot spots' of malnutrition and infection need further study. Their combined effects have been labelled the 'malnutrition-infection complex' (Tomkins et al., 1989), suggesting a recurrent cycle of interaction which amplifies the impact of one or other vector in reducing the nutritional status of the affected populations.

Usually, population sub-groups are differentially affected, with the most vulnerable having that combination of socio-economic and health factors which either facilitates the onset of malnutrition or infection, or inhibits recovery. In the 1980's attempts were made to create vulnerability maps in Bangladesh and Sudan (Borton and Shoham, 1989; Currey, 1993) to identify the local areas most exposed to the risk of famine. In general, such systems compute an aggregate index of vulnerability, using local 'experts' to subjectively weight the indicators of the underlying socio-economic and health factors. This index is then overlaid on large-scale maps to assist the targeting of food aid in the event of an emergency arising. Subsequently, the manual mapping has been replaced by the use of Geographic Information Systems (G.I.S.). These also facilitate the aggregation of the weighted indicators by allowing each indicator to be treated as a separate map layer within the G.I.S. (Hutchinson, 1991). Three organisations: Save the Children Fund (S.C.F.) (Seaman et al., 1993), Medecins sans Frontieres (Dusauchoit, 1994) and the United States Agency for International Development (U.S.A.I.D.) (1992) are taking 'vulnerability mapping' further. They

are developing computerised systems to identify vulnerable localities and population sub-groups, by reference to a series of indicators derived mainly from secondary data sources, but augmented by specially commissioned field surveys to monitor, for example, market prices of staples.

Based on historic information, these systems are essentially reactive, with limited predictive power. Typically, the S.C.F. model identifies potential malnutrition on a near-current basis, providing targets for localised food aid deliveries of bulk supplies already in the area. Essentially, therefore, the process in use by aid agencies can be thought of as comprising two distinct stages: (a) crop forecasts / early warning systems to identify the regions likely to need assistance and initiate the dispatch of bulk food aid, followed by (b) targeting / vulnerability mapping to identify the local areas and the population sub-groups to which aid should be allocated. In effect, the current position has a discontinuity in time horizon between the 'earliness' of the early warning systems and the immediacy of the targeting models.

1.8 Potential for simulation

Obviously, this discontinuity in time horizons should not be resolved by shortening the outlook period for the early warning systems. The need is to link the targeting models more closely to these systems and use the wide area predictions to drive localised models dynamically and so simulate food system performance over an extended time period, ideally an agricultural year. The targeting systems should offer more potential to review the outlook for localised food systems and the impact of shortages on the communities' nutritional status. In other words, if the early warning system, by the second month of the growing season, is forecasting a poor harvest in the east of Zimbabwe, the targeting model needs to be able to simulate the impact of this harvest shortfall on the communities in the region, identifying those most probable to suffer from reduced nutritional status.

Although forecasts of harvest performance provided by the early warning systems will be a significant influence upon a simulation model of the localised food system, other data about disease and macro-economic changes will be needed. Data will also be required about the communities themselves and their local natural and socio-

economic environment. In many countries in sub-Saharan Africa, such data are already collected and collated as a matter of routine by various government ministries, parastatals and trade associations at central, regional and local level. These secondary data usually offer national coverage and an extended time series. In the longer term, if such data were routinely utilised in any simulation model, they would provide a comprehensive and consistent perspective in analysing local food systems. Data collected for one purpose are rarely ideal for use in other projects. However, secondary data have robustness in their temporal and spatial coverage that may justify the investment in making modifications to their reference frames prior to use in a model. As an example in Zimbabwe, data are collected for agriculture by communal land areas, for health by clinic and for the census by ward. Using G.I.S. overlay techniques to apportion areas, these data have been successfully combined using the ward as the common unit of aggregation. In spite of this additional processing requirement, use of secondary data should remain cost efficient when compared to the commissioning of primary surveys or *ad hoc* comparative analyses of existing data.

The simulation of localised food systems and thereby the forecasting of changes in the nutritional status of communities may offer an advantage over more conventional techniques based on aggregated secondary data. Tagwireyi and Greiner (1994) have suggested that the malnourished population in a given rural area of Zimbabwe comprises some individuals who are malnourished because of infection, some who are malnourished because of inadequate food access, and some who are malnourished because of problems related to parental care. As such processes are essentially determined at household level, they need to be represented explicitly, by simulating the food system from the household level upwards, to reflect the multiple causes of malnutrition.

Representing rural communities, such as the Buhera District in Zimbabwe, by multilevel spatial and temporal simulation models, with explicit links between the various hierarchical levels, may enable the impacts of micro-level events on macro-level phenomena to be observed. Micro-simulation studies in other areas, notably traffic flow models such as TRANSIMS (Rasmussen and Barrett, 1995) have shown that summing the output of low-level models can produce more realistic simulations of real-world phenomena than the use of aggregate flow models. The implication

here is not that ‘the whole is greater than the sum of its parts’, but rather that careful aggregation from micro-level upwards may reveal effects under specific combinations of circumstances that would not be accurately represented in a macro-level model. Nonetheless, great care needs to be exercised in the implementation of such models, particularly to ensure that interactions between ‘agents’ (e.g. vehicles in TRANSIMS, households in this work) and transactions across hierarchical levels are internally consistent within the context of the model. Boundary conditions – both temporal and spatial – are a particular problem in this regard. If such problems can be overcome, models of this type may offer a novel approach to the modelling food systems and the nutritional status of communities. In the long term, they may also be of use in the evaluation of policy initiatives and the selection of the most appropriate intervention point in the socio-economic hierarchy. As Taylor and Adelman (1996) remark (p. 3): ‘Understanding the likely impacts of policy, market and environmental changes on rural incomes requires understanding micro-responses in household-farms, the complex linkages among household-farms within villages and the linkages between villages and the outside world.’

1.9 Outline of following chapters

The second chapter, a literature review, examines other authors’ views about malnutrition, its underlying causes and the various approaches to reporting and modelling its effects. An economic view of food shortages is presented, focussed around the work of the recent Nobel prize winner, Amartya Sen. Various approaches to the socio-economic modelling of villages and households are reviewed, including recent works that take a ‘livelihoods’ approach to rural communities. The impact of environmental risks and households’ coping strategies in response to these are outlined. Malnutrition statistics for developing countries show marked seasonality and the implications of this seasonality are discussed. The background and conceptual framework of food security and the interaction of infection with malnutrition are examined. The monitoring of food shortages and targeting of food aid by governments, international agencies and N.G.O.s are described. The review also examines how the food system and the nutritional status of the population might best be modelled. It concludes with a summary of the implications of the literature for this research.

In chapters 3 and 4, the characteristics of the study district of Buhera in Zimbabwe are described and the sources of data for the building of models are discussed. In chapter 3, the household survey, representing a one percent sample of the study district of Buhera, is outlined. The stratified random sample frame and the methods of data collection are described, including the direct measurement of all household members by anthropometry. Particular attention is given to the collection of data across the agricultural season with multiple survey rounds. Summary results of the household survey, showing the spatial and temporal variability of nutritional status and the household factors are presented. In chapter 4, the various secondary data sources are reviewed. The usefulness or otherwise of particular datasets for input to a simulation model is summarised. Where secondary data have different spatial aggregation units or relate to different collection times, the methods used to adjust these are outlined. This chapter also describes briefly an 'Index of Infrastructural Vulnerability' developed to represent the slowly changing processes in the local food system and the reasons that this index was not pursued further within this work.

Chapter 5 describes the use of systems dynamic modelling to develop an appropriate framework for the simulation of the food system of Buhera. Prototype models of the food access and health components are detailed together with sample output.

Although the systems dynamic modelling offered an appropriate method for simulating temporal change, the approach was deficient in that spatial variability and the heterogeneity of households' characteristics were not easily incorporated within the modelling framework. This chapter concludes by discussing the implications of this deficiency for future development of the framework.

The sixth chapter takes stock of the various design considerations that formed the basis of the development of the second framework. It looks in more detail at the implications of spatial and temporal variability. The hierarchical structure in the socio-economy of Buhera District is described. The heterogeneities that exist within each layer of this hierarchy are discussed, including the implications of this for representation of individual households, wards and agro-ecological zones. Grain trading is reviewed and particular attention is given to Vaze's (1999) work, which provides an economic model for determining price in rural markets. Of particular

importance is the recognition that transactions, relevant to the operation of the food system, occur within layers (sales / purchases of grain between households, for example) and between layers (sales / purchases of grain by households to traders). A concept of 'Communal Inter-Active Object' (C.I.A.O.) is described and the method by which this influenced the second modelling framework design is discussed. The distinction between modelling processes and discrete events is discussed in relation to the behavioural rules and transactions in the food system. Other design considerations relating to simulation control and processing consistency are outlined. The need for special consideration of short term factors: rainfall, disease rates and economic variables is discussed. Methods by which output will be provided to users are discussed. The validation of models is discussed, including the limited potential to compare simulation results with independent data. An example is given of the difficulties in respect of malnutrition where validation will be restricted to children under five years of age as clinic statistics exist only for that cohort. The problems of calibration of models, which suffer from similar limitations to those for their validation, are outlined. Methods for implementing the second framework are discussed: the use of an agent-based software tool and an expert systems simulation, the latter being the chosen route.

In chapters 7, the design of the modelling framework and the three main components: the population database, the short-term factors and the behavioural rules are described in detail. The overall design of the framework is described and its modular structure emphasised. It enables the implementation of simulation models encompassing one year, commencing at the beginning of the agricultural season in November and proceeding in time steps of a 'dekad' (approximately ten days). This choice of simulation time step is discussed. A description of the population database is provided. This database stores the static and dynamic resources of each object within each hierarchical layer and is a restricted replication of Buhera District's households, wards and agro-ecological zones. It is an extrapolation from the household survey and secondary data, using the aggregate values from the 1992 census as control totals. A description of the statistical analysis method used to carry out this extrapolation is provided. The changes in dynamic resources of households, wards and agro-ecological zones are controlled by the behavioural rule base, which is described in detail. This rule base is the extensible element of the model and can accept a wide

variety of rule formats, including mathematical expressions, complex case statements and simple logical predicates. Transaction rules are also implemented which ensure accounting consistency between objects and between layers for all sales, purchases and transfers of food, crops, livestock and cash. The rules themselves are provided by users and are derived from literature sources, data analysis and by encoding the opinions of 'experts'. The simulation engine controls the rules that are attached to each level of the model and 'fires' them in sequence for every object in that level at every time step of the simulation. The short-term factors of rainfall, illness and economic change are generated externally and provided to the model as a series of separate database files, selectable by the model user to set the required simulation parameters. The rainfall module has been derived from an analysis of meteorological station data and provides ward level rainfall estimates for each dekad. The illness module is based upon the reported illnesses of respondents in the household survey. The module of economic change is currently restricted to a simple file of Grain Marketing Board (G.M.B.) price data for the four crops modelled in the simulation: maize, sorghum, groundnuts and a generic cashcrop, together with inter-ward transfer costs and interest rates.

The final chapter reviews the strengths and weaknesses of each section of the work. It discusses the effectiveness of the second modelling framework. The direction for the future development of the model is discussed, suggesting the extension of the single year simulation to a longer period for the cost-effectiveness analysis of interventions and the comparison of rural development policies. The chapter concludes by summarising the extent to which the objectives of the work (as set out in section 1.2) have been achieved.

1.10 Remarks

Devereux (1993) comments (p. 29) 'If an economist writes about famine, then famine is caused by market failure or lack of purchasing power. If a climatologist writes about famine, then famine is caused by drought or desertification.' Rather than view malnutrition and famines from any single standpoint, this thesis aims to offer a broad church in which different perspectives can be reconciled through the medium of a modelling framework, by coherently linking the various disciplinary sub-models.

It will be observed, from both the thesis title and this chapter, that the author is limiting his presentation herein to matters concerned with the design of the modelling framework and not to the implementation of the simulation model itself. The latter is the responsibility of the collaborative research project and is not yet complete. Notwithstanding this separation of responsibilities, various components of the research project, in particular the primary and secondary collection, are presented herein as they are germane to this thesis, providing the necessary information to support the design of the modelling framework.

2 Literature Review

2.1 Purpose

This literature review is concerned with the economic and nutritional aspects of food security and malnutrition, with particular attention to the temporal and spatial variability of the processes underlying local food systems in developing countries. It also reviews the various approaches that have been used for forecasting and modelling the behaviour of food systems in southern Africa and the various generic modelling techniques that may be applicable.

2.2 *An economic view of food shortages: Sen's entitlement approach*

Before examining the economic models that relate more specifically to community-level food systems, the seminal work of Amartya Sen on famines deserves mention. Although the work herein is concerned with the more general problem of forecasting malnutrition, Sen's approach offers an insight which that has applicability to the way in which a household obtains, or has access to, food.

In common parlance, most people would probably regard a '*famine*' as a severe case of a food shortage. Indeed, the dictionary definitions quoted by Devereux (1993) all echo this idea to some extent, with the implication that it is a problem of *food supply*. This should be contrasted with the now famous two opening sentences from Sen's book (1981) in which he reviews and updates his important analysis of the great Bengal famine of 1943: '*Starvation is the characteristic of some people not having enough food to eat. It is not the characteristic of there being not enough to eat. While the latter can be a cause of the former, it is but one of many possible causes.*'

Devereux (ibid.) analyses the differences between the various *Food Availability Decline* (F.A.D.) and *Economic* theories within his wide review of the various theories of famine. He cites (p.31) the disciplinary-based taxonomy of famine theories of Leftwich and Harvie (1986), shown below:

- (i) Food Availability Decline (F.A.D.)
Population increase (Malthus); War; Climatic factors
- (ii) Ecological mismanagement
- (iii) Socio-economic or political dislocation in the course of development
- (iv) Economic theories
Market failure (Alamgir); Exchange entitlements (Sen)
- (v) Government mismanagement / political or institutional failure
- (vi) Anthropological or sociological explanations
- (vii) Multi-causal or eclectic approaches

Sen's basic argument, developed in an earlier publication (Sen, 1977), is as follows:

Each of us within a private ownership market economy has a set of entitlements, the main four being:

- (i) **Trade-based entitlement:** one is entitled to own what one obtains by trading something one owns with a willing party (or, multilaterally, with a willing set of parties);
- (ii) **Production-based entitlement:** one is entitled to own what one gets by arranging production using one's own resources, or resources hired from willing parties meeting the agreed conditions of trade;
- (iii) **Own-labour entitlement:** one is entitled to one's own labour power, and thus to the trade-based and production-based entitlements related to one's labour power;
- (iv) **Inheritance and transfer entitlement:** one is entitled to own what is willingly given to one by another who legitimately owns it, possibly to take effect after the latter's death (if so specified by him).

With these entitlements each of us has the ability to acquire a set of alternative commodity bundles. In non-famine times, these commodity bundles would include food goods sufficient for our needs. In famine times, however, there is no commodity bundle to which the starving person has access that contains sufficient food to sustain him. Or as Sen (1981) puts it, the endowment of a person (his resources) cannot

command an exchange entitlement set of commodity bundles satisfying his minimum food requirements.

Devereux (ibid.) (p.82) notes that Sen's entitlement approach has been dismissed by some as an elegant, academic way of saying nothing more than 'people starve because they can't buy enough food'. Nonetheless, it has endured the various criticisms and continues to influence much of the famine analysis of governments, international agencies and academics. Devereux quotes Crow's (1986) (p.4) remarks '...the (entitlement) approach has moved the presumption of famine causation from production to distribution, and has specifically, placed household purchasing power at the centre of investigation.'

Of the many criticisms of Sen's approach, three are perhaps of most relevance to the work herein: market failure, intra-household food distribution and excess mortality brought about by an adverse disease environment. An additional criticism, that the theory is of its nature, static, also requires comment.

In relation to market failure, the distinction must be drawn between 'pull failure' and 'response failure.' The former refers to the inability of consumers to purchase adequate food, due to lack of money or exchangeable goods / services and is precisely the issue addressed by the entitlement approach itself. The latter, however, may arise when consumers, although having the necessary purchasing power are frustrated in their attempts to acquire food by the lack of a market in which to buy. In sub-Saharan Africa, this response failure can be seen in rural areas, where subsistence households that normally produce sufficient food for all or part of the year are affected by crop failure and become consumers, looking for markets in which to purchase grain. Because of the sparse populations and inconsistent agricultural performance, traders are reluctant to visit many of these rural areas, with all the high attendant transactions costs, preferring to remain in better defined and more populated markets, albeit with potentially lower prices. Additionally, in many sub-Saharan African countries, parastatal grain marketing boards control the distribution channels and these are often established as 'uniflow' systems to transfer rural surpluses to urban consumers, via the milling companies. As Rukuni and Jayne (1995) remark (p.20) in relation to Zimbabwe 'The Grain Marketing Board (G.M.B.) does not view its mandate to

include the distribution of grain from surplus rural areas to deficit rural areas.’ Often the only recourse for rural consumers, unserved by traders or local markets, is to travel long distances, with high opportunity cost, to purchase grain in more established markets.

Ravallion (1987) discusses the operations of markets and their impact upon famines, from an economic perspective. His beguilingly simple closing sentence (p.174) ‘The causation of famine involves a lot more than bad weather and its relief requires much more than aid’ follows a rigorous analysis of famines in India and Bangladesh and the markets in the affected areas. Ravallion uses a ‘health production function’ to evaluate how prices and incomes generated by markets can influence human survival chances. He derives a survival function from this health production function and a probability density function of personal constitution, showing that the curve of the survival function is concave in shape, for all but low levels of consumption. He observes (p.27) that ‘...this is in accord with the limited empirical evidence. ... the increase in survival chance falls as consumption increases until, eventually, extra consumption has negligible benefit.’ He also notes three implications of concavity: (1) that survival to terminal date is maximised by equalising consumption over time i.e. that intertemporal consumption transfers confer survival benefits; (2) that by similar reasoning, transfers from ‘high’ grain consumers to ‘low’ ones will raise the joint and average probability of survival in the population and (3) that strict concavity will produce larger increases in mortality for each subsequent reduction in consumption, for a series of equal reductions i.e. high mortality can arise through a series of slow, but steady food reductions rather than through some exogenous event or shock.

In addition to the food markets of the Indian sub-continent, Ravallion (ibid.) looks at the agricultural labour markets in Bangladesh around the time of the 1974 famine. He shows that after the famine, possibly as a result of an excess supply of rural labour caused by enforced land sales, the real rate of agricultural wages fell. Also, in the short term, during the famine, wage rates fell at a time when rice prices increased sharply. Ravallion sees this as evidence for the disruption of social customs, including payment systems during the famine.

Ravallion concludes his 1987 work by discussing the policy issues arising from his analysis. He observes:

- **Distribution of emergency relief aid** – to maximise the number of people who survive to an arbitrary future date (i.e. to minimise mortality), allocation on the basis of need may be sub-optimal, especially given the ‘noisy’ nature of the information used to assess such need on an individual, household or community basis. Where a population comprises individuals having varying survival functions, it may be preferable (to minimise aggregate mortality, rather than having regard to any moral argument) to allocate food aid to those in less need but with a higher chance of survival after the handout.
- **Buffer stocks** – by stabilising prices, buffer stocks reduce the incentives for private speculation and thus of intertemporal storage and hoarding by traders and others. Ravallion demonstrates that in perfectly competitive markets, buffer stocks replace private stocks on a one-to-one basis and are thus ineffective in stabilising prices. In imperfect markets, he shows that public storage will indeed stabilise prices, by reducing private storage in a greater ratio than unity. However, at low levels of buffer stocks, the effect can be reversed as traders perceive a possible imminent run down in public stocks as an indication that future price rises will occur.
- **Trade** – although Ravallion shows that free trade does not appear to stabilise aggregate domestic food availability, he suggests that trade taxes that enhance the responsiveness of external trade to domestic prices may offer scope for effective intervention. Under such a scheme, exports are taxed (or imports subsidised) when output is below normal whilst at all other times exports are subsidised (imports taxed). He notes that such schemes have inherent tax revenue instability and will require the use of a monetary buffer, as promoted through use of the IMF’s food financing facility.
- **Public information** – Ravallion emphasises the extent to which the informational inefficiencies of markets are destabilising. His study of Bangladeshi rice traders’ expectations revealed their tendency to overestimate price changes, influenced too heavily by current trading patterns and an apparent inability to ‘learn’ from past forecasting errors. He suggests that a fruitful intervention might well be to

monitor and publish the traders' expected prices, in addition to the existing publication of current prices. He notes that the use of 'heuristics' by traders causes an over-reaction to new market information, an observation echoed by psychologists studying how people deal with uncertainty.

- **Food aid as an income supplement** – where famine victims have suffered a complete collapse of their exchange entitlements, aid will be their sole source of income. For others, aid will supplement their other sources of income and its aggregate effects on prices can produce a 'feedback' response as recipients purchase goods and/or services, or hire their labour. Ravallion shows that for segmented markets, food aid will have both a beneficial direct effect (more income, as the imputed value of the food received) and a beneficial indirect effect of reducing market prices for staple foodstuffs as a result of the increased aggregate supply. In a stable and competitive exchange economy, however, transfer of a commodity will raise its relative price if the donor has a lower marginal propensity to consume that commodity than does the recipient. The indirect price effects will thus mitigate the direct benefits of the aid received. 'Food for work' programmes are also reviewed and Ravallion finds that such schemes do indeed raise rural incomes, provided that the elasticity of demand for labour in rural areas does not exceed unity.

Sen's treatment of the household as having a unitary set of entitlements and ignoring intra-household distribution issues is very much in line with the earlier approach of Becker (1965). He takes an inclusive view of family and household, seeing one set of preferences determining the combination of time, goods purchased in the market and goods produced at home to generate utility for the household. As Haddad (1994) observes (p.348) '...the unitary view of the household can have serious consequences for policy design, implementation and evaluation.' He discusses the alternatives of cooperative and non-cooperative collective models of the household, noting that all allow the different decision makers within the household to have different entitlements and preferences, giving rise to differences in allocation of resources within the household. In a later collection of papers edited by the same author (Haddad et al, 1997), Thomas (1997) analyses the intra-household distribution of income, using data from Brazil, concluding (p.164) 'It appears that, as income under

the control of women rises, more is spent on health- and nutrition-related expenses. The evidence of child health outcomes is consistent with this interpretation: maternal income has a significantly larger effect on the weight-for-height and height-for-age of children than paternal income.’ The implication for the design of the modelling framework of intra-household distributional disparities is the need to ensure that their impact upon individuals (or perhaps cohorts) within households can be distinguished in the implemented models.

In reviewing Sen’s approach, Devereux notes (p.77) the inability to explain the excess mortality during famines that is not (directly) related to starvation. He cites de Waal (1990), who reports that during the 1984/85 famine in Darfur, Sudan, the mortality in refugee relief camps was not correlated with socio-economic group, but rather by an increased exposure to infections and diseases. In de Waal’s paper (ibid.) he observes (p.479) that ‘empirical findings concerning famine mortality suggest that ‘disease-driven’ mortality is a central fact of famines’. He amplifies these ideas and comments (p.483) ‘A refinement of Sen’s position on famine mortality would therefore see it as an outcome of two factors. One is entitlement to staple food, which when it has wholly failed, leads to starvation and an increased risk of death. The other is the disease environment, which is an outcome of the normal disease environment of the society in question, and the disruptions visited upon that by the famine.’ de Waal labels this as his ‘health crisis’ model of famine mortality, according to which ‘all the excess mortality is attributable to a changed disease environment *consequent on the social disruption entailed by drought and famine* (my italics), including drying wells, population crowding in larger villages and towns, and the breakdown of sanitary facilities.’

The italicised phrase in the latter quotation exemplifies de Waal’s and (apparently also) Devereux’s views that changes in disease environments occur consequentially to entitlement failure and are limited to refugee camps and informal communities. Neither author seems to suggest that the changes in disease environments can also occur in parallel with the processes of entitlement failure, for example to those suffering malnutrition and starvation in their own households. This contrasts with Lindskog (1988) who comments (p.266) ‘available data indicate that malnutrition leads to altered immune response with prolonged and more severe attacks of

infections'. This suggests that interaction between the effects of malnutrition and the disease environment is the preferred physiological (cf. economic) model of morbidity and mortality during and after famines.

Ravallion's (1996) paper is essentially a robust defence of Sen's entitlements approach and takes a broader economic perspective of famines than the influence of markets, as was covered by his earlier book (Ravallion, 1987), reviewed above. In taking as its starting point the work by Sen (1981), Ravallion reviews more recent analyses by other authors and is critical of some of the objections raised to the entitlements framework. In particular, he stresses that Devereux's (1988, 1993) interpretations of Sen's proposal of entitlement failure as a 'demand side' explanation of famines, contrasted with the 'supply side' explanation provided by the Food Availability Decline ('FAD') theories, is a misunderstanding and is not well founded in Sen's writings. His view is (p.6) '...that the entitlements approach should be seen as an encompassing framework, within which food availability is only one parameter.' He also discusses the criticism that the theory is 'static' (cf. dynamic), by observing that the entitlements approach can encompass intertemporal choices, whereby households and/or individuals within them choose a degree of hunger at time of famine in order to avoid starvation at a later date. He maintains that forgoing current consumption to maintain asset levels is not inconsistent with Sen's framework.

Ravallion sees the two more substantive issues raised in objection as (a) the conditionality of what constitutes an 'entitlement' upon the legal system in place and continuing in place in the affected country and (b) the role of health. For the former, he distinguishes (p.7) between '...the collapse of ... informal arrangements for risk-sharing ... from the collapse of the legal apparatus which defines and enforces property rights.' He maintains that whilst the informal arrangements often collapse during famines, the legal system generally does not. On the role of health, Ravallion seems less sure of his ground. He accepts that it is rather a simple view to see mortality at times of famine as being determined by a failure to reach some well-defined consumption level, rather weakly observing (p.8) 'There is clearly latent inter-personal variability and, hence, uncertainty about survival prospects.' But, Ravallion also observes '...exposure to disease of *migrating* (my italics) people

during a famine is not exogenous, but (it can be argued) an outcome of the same entitlement failures which led to migration in search of food.’ The italicised emphasis seems to echo the views of de Waal discussed above (in seeing the disease environment as a consequence of entitlement failure rather than occurring in parallel with it).

Perhaps the sections of Ravallion’s (ibid.) paper most relevant to the work of this thesis are the observations about variability of individuals, households and communities and the diversity in the welfare impacts that arise at times of famine as a result of such differences. He observes (p.11) ‘Households with chronically poor endowments, or whose endowments have been run down by a series of shocks, will be particularly vulnerable. Net trading position in food markets also varies amongst the poor. Peasants with enough land to be net producers of food will gain from higher food prices, but other peasants and landless laborers will probably lose, though even amongst the latter group some will be protected by longer-term contracts.’

von Braun et al. (1999) offer a multi-layered, comprehensive analysis of famine, encapsulated in the diagram in Figure 2.1. below. The authors note (p.9) that it is in Layer IV that failure of entitlements is most evident - when income and consumption failure interacts with the collapse in services and distress migration.

Though this diagram has much to commend it by setting the household layer against the broader socio-economic, institutional and political environment, it is noticeable that there is no mention of the impact of health at any layer. This issue of the interaction of health with consumption - the ‘malnutrition-infection complex’ - is discussed in section 2.7 below.

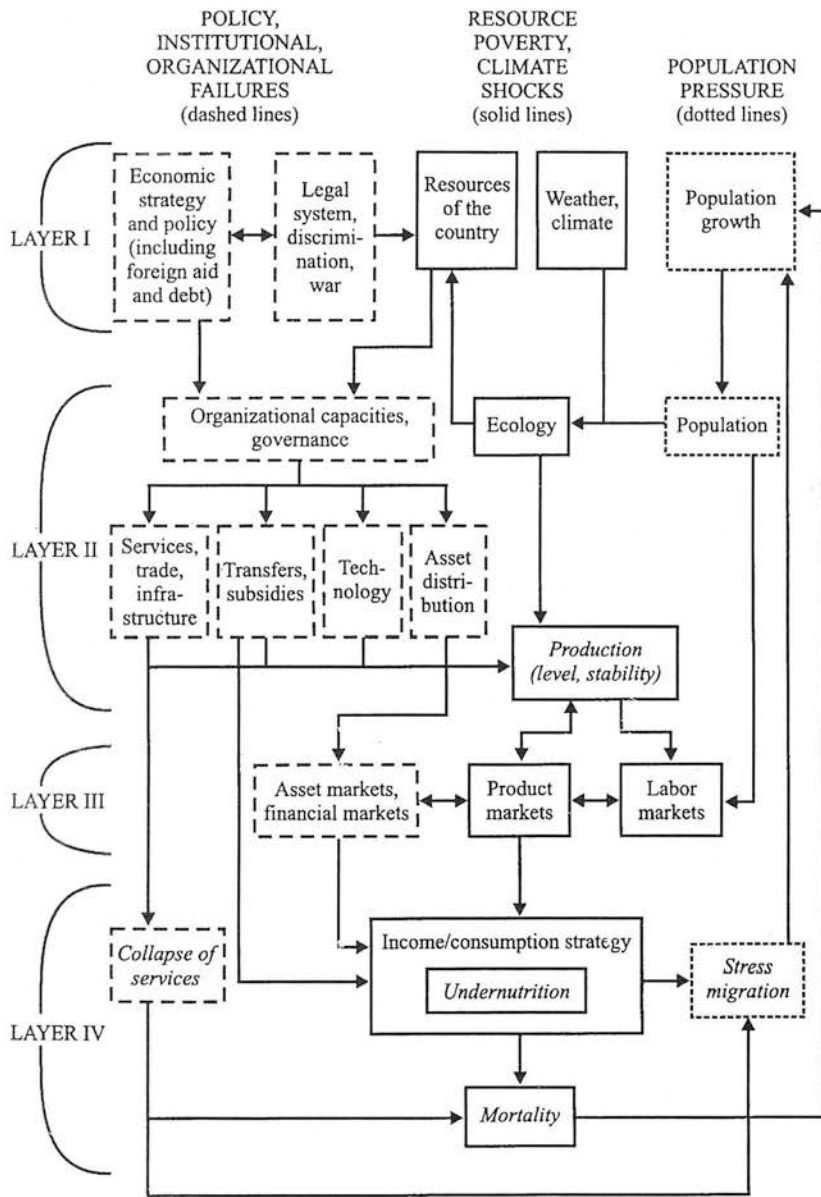


Figure 2.1 Determinants of and relationships in famines (von Braun et al., 1999)

Finally, before leaving Sen's theory of entitlements, mention must be made of its essentially static (cf. dynamic) perspective of famines as 'events', rather than as part of the continuum of moderate malnutrition / severe malnutrition / starvation affecting proportions of the population. There are two aspects to this. Firstly, the theory focuses on the famine event itself and the immediate outcomes. Devereux (ibid.) notes (p.80) Bush's (1985) criticism that this 'conjunctural' analysis leads to undue emphasis upon the short term circumstances leading up to the famine – the marketing and distribution of food immediately prior to the event – rather than upon the linkages

between the distributional anomalies and the longer term economic and social factors. Secondly, the emphasis on a single 'event' avoids the need to analyse the famine itself as a dynamic process (or indeed, as part of a larger process). Devereux cites several authors who are critical of this implicit 'event' model in Sen's work and da Costa (1986) suggests combining a dynamic approach to entitlement change with individual and socio-economic group vulnerability analysis to produce what might be called a 'dynamic entitlement system analysis'. Ravallion (1996) also sees (p.16) 'the most serious limitation of the above discussion (*on entitlement failure*) is that it has been largely static.' He reviews Carraro's (1996) dynamic model of famines, supporting the plausibility of Carraro's assumption that agricultural output in any given period is dependent upon the labour inputs in prior periods. He notes, with reference to Dasgupta (1993) that 'The usual static productivity-nutrition relationship can be interpreted as the steady state solution of a dynamic of energy-conservation equation; the static relationship assumes that there is no change in the body's stock of stored energy. For the purposes at hand one would not want to make that assumption; people starving in a famine will be running down their stores.' Indeed, the variability in the body's stock of stored energy has been observed by several authors, see for example Ferro-Luzzi et al. (1992, 1994) who report significant intra-seasonal variability in nutritional status amongst subsistence farming populations in Zimbabwe and elsewhere. These various ideas of dynamic, as opposed to static, views of the changes in entitlements have much to commend them as possible bases for the simulation of the food system.

Devereux (2000) summarises (p.20) the fundamental problem with Sen's theory and extensions of it 'Despite its elegance and simplicity, the one thing that the entitlement approach did not offer was an explanation. It showed how people might face starvation during famines: it did not tell us why. By choosing to restrict his analysis of famines to the relationship between people and markets under stress, Sen perpetuates a technocratic view of famine that excludes politics and intent as causal factors, and *political* action (rather than '*public* action') as an appropriate - even necessary - solution. Famine is seen as a temporary convulsion of the economic system, requiring nothing more than welfarist transfers to vulnerable groups who are temporarily unable to meet their subsistence needs.'

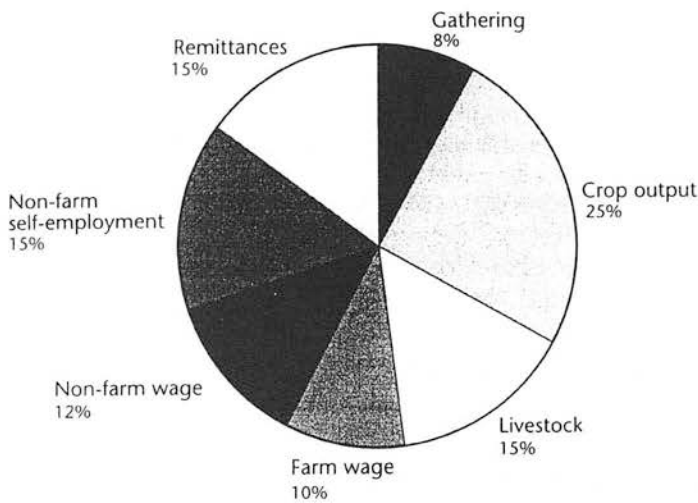
2.3 Village and household economic models

Several authors discuss the socio-economic modelling of households and rural communities in developing countries. These models are conceived to represent the 'normal' functioning of the households and villages, rather than restricting the analysis to the effects of famine and other 'temporary convulsions of the economic system' (Devereux, *ibid.*).

Ellis (2000) starts his recent book 'Rural Livelihoods and Diversity in Developing Countries', as follows: 'This book is about livelihoods, diversification, and the survival strategies of rural households in developing countries. Its key point of departure is that for many such households farming on its own does not provide a sufficient means of survival in rural areas. For this reason most rural households are found to depend on a diverse portfolio of activities and income sources amongst which crop and livestock production feature alongside many other contributions to family well-being.'

He notes that this diversity poses problems for economic and social analysis. In particular he observes that attention has been focussed over many years upon the small farm household (my emphasis) in developing countries, examining its functioning as an agricultural enterprise rather than its dynamic pluriactivity.

He cites several studies (Haggblade et al., 1989; von Braun and Pandya-Lorch, 1991; Sahn, 1994 and Reardon, 1997) that demonstrate that in contemporary poor countries, the maintenance and continuous adaptation of a highly diverse portfolio of activities distinguish rural survival strategies.



Livelihood comprises :

- Assets
 - natural capital
 - physical capital
 - human capital
 - social capital
 - financial capital
- Activities (as shown)
- Access mediated by
 - Institutions
 - land tenure
 - common property
 - real markets etc.
 - Social relations
 - village
 - ethnicity
 - gender etc.
 - Organisations
 - government agencies
 - community groups
 - NGOs etc.

Figure 2.2 A diversified rural livelihood (Ellis, 2000)

Ellis (ibid.) defines (p.10) livelihood as follows: 'A livelihood comprises the assets (natural, physical, human, financial and social capital), the activities, and the access to these (mediated by institutions and social relations) that together determine the living gained by the individual or household.' But he immediately cautions that such a definition '...fails to convey change over time and adaptation to evolving circumstances.' He classifies income arising in the household, from the various activities, as Farm Income (own account farming), Off-Farm Income (wage or exchange labour on other farms i.e. within agriculture, and perhaps the harvesting of local environmental resources) and Non-Farm Income (non-agricultural sources:

wages, rents and urban-rural remittances, including pensions). He provides (p.16) the diagram of a diversified rural livelihood, shown in Figure 2.2 above.

To some extent, Ellis recognises that diversity arises from the nature of the household as a social unit, with social diversity giving rise to income diversity and access to sources spatially distant from the household. Thus he notes (p.20), ‘... Baber (1998) utilises a concept of the household in which four overlapping definitions of social units - homestead units, family groups, co-resident groups, and mutual-support units – are mapped against income generating characteristics described as simple-resident, simple-dispersed, extended-resident and extended-dispersed.’ Furthermore, he observes (p.23) ‘...closer to reality in contemporary sub-Saharan Africa, highly diverse household livelihood strategies may occur in the context of a relatively undiversified rural sector.’ Ellis emphasises the need to analyse households via an ‘assets-mediating processes-activities’ framework, in which the asset status of poor households is fundamental to the understanding of the options available, the strategies adopted and hence their vulnerability. He presents this framework (p.30) as the diagram in Figure 2.3 below, adapting earlier work by Scoones (1998) and Carney (1998).

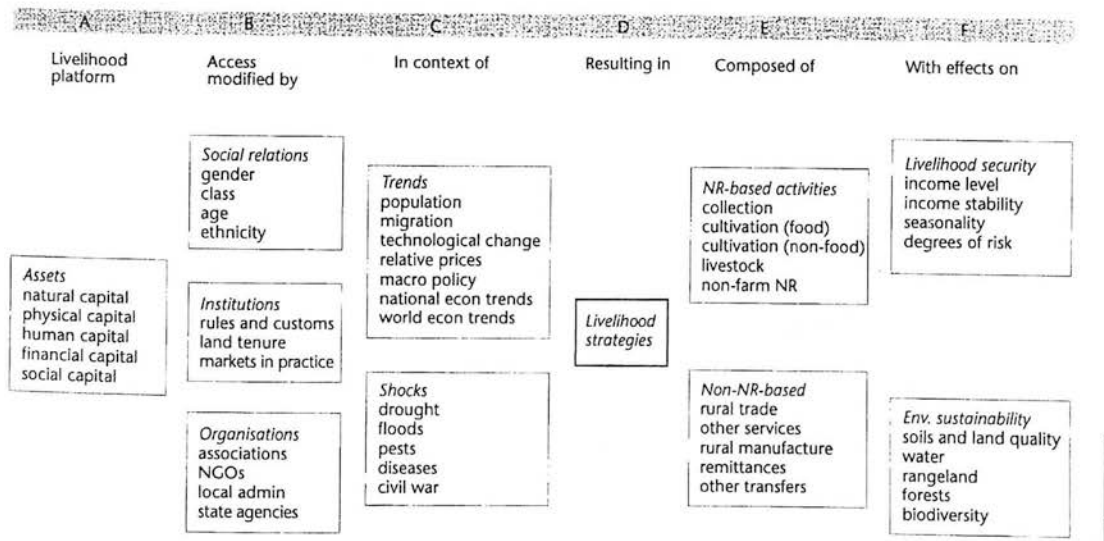


Figure 2.3 A framework for micro policy analysis of rural livelihoods (Ellis, 2000)

Ellis acknowledges the limitations of this diagram in capturing the essential dynamics of livelihood systems, noting (p.29) that these ‘...involve innumerable feedbacks and complex interactions between components.’

In the chapters that follow, Ellis concentrates on the means by which poverty can be measured and analysed, including some interesting approaches using radial graphs (see for example p.49 and p.226) to assess asset status and changes therein. Although the Tanzanian case study (chapter 10) includes the use of income portfolios to construct typologies of livelihood strategies (see for example, p.210), detailed discussion of how the ‘processes-activities’ half of the framework might be analysed as a system is largely avoided. Rather than present an overall view that shows how each of the components are linked, Ellis subsumes the diversity of activities within a more traditional approach of analysing agriculture and farm productivity (see chapter 5) and links to issues of environment and sustainability (chapter 6) and gender (chapter 7). In the chapter on gender, he observes (p.140), ‘...these economic models remain analytically static in nature, and they are unable to capture the renegotiation and adaptation of gender roles that occur in practice when households are caught up in changing circumstances that threaten the viability of their existing livelihoods.’

This work by Ellis (2000) draws on other authors such as Scoones (1998), Reardon (1997) and Carney (1998a), who all discuss the livelihoods approach to household analysis and the diversity of incomes associated therewith.

Scoones’ (ibid.) short paper approaches the issue from the standpoint of sustainability of livelihoods, defining (p.5) ‘A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, while not undermining the natural resource base.’ Scoones identifies four types of capital, which he suggests determine the feasible livelihood strategies available to an individual, a household or a village (p.7):

- **Natural capital** – the natural resource stocks (soil, water, air, genetic resources etc.) and environmental services (hydrological cycle, pollution sinks etc.) from which resource flows and services useful for livelihoods are derived.
- **Economic or financial capital** – the capital base (cash, credit/debt, savings and other economic assets, including basic infrastructure and production equipment and technologies) which are essential for the pursuit of any livelihood strategy.
- **Human capital** – the skills, knowledge, ability to labour and good health and physical capability important for the successful pursuit of different livelihood strategies.
- **Social capital** – the social resources (networks, social claims, social relations, affiliations, associations) upon which people draw when pursuing different livelihood strategies requiring coordinated actions.

These give rise to the livelihood strategies adopted, which Scoones calls 'livelihood portfolios'. He suggests (p.11) that previous approaches to the study of rural livelihoods has shown '...disciplinary bias whereby economic analysis which has concentrated on exploring the quantitative relationships between measurable variables'. He argues that sustainability in livelihood strategies is only achieved through effective '...social structures and processes' (p.12) and that understanding of these must emphasise the study of institutions and organisations. In his closing remarks (p.14), he recognises that '...experience of multi-sectoral and integrated development has not always been positive' and cautions that the livelihoods framework is not necessarily a good guide to intervention. But, perhaps his most useful policy recommendation is (p.14) '...going beyond the sectoral approach to rural development' such that '...if the development objective is to create and sustain livelihoods, then agriculture, off-farm income generation, migrancy and remittances have to be looked at together.'

In contrast to Scoones, Ellis (2000) is rather cynical of the use of 'sustainable' (preface p.X) '...sustainable has become one of the most over-used and degraded words in development studies, rendered practically meaningless by the multiple aspirations it seeks to placate.' Certainly there is a sense in which Scoones' paper appears to have been written with the intention of appealing to populist and

fashionable notions of rural development, but if this gives his message of 'joined-up thinking' greater currency, then this must be to his credit. Of more serious concern, in this author's view, is that although Scoones claims to have presented a framework for the analysis of sustainable livelihoods, this comprises a conceptual diagram with little guidance as to how this can be translated into a comprehensive model. In his section on 'Methodological considerations' (p.13), Scoones himself notes 'Investigating each element laid out in the framework...is potentially a significant undertaking. If the full range of differentiated and nuanced quantitative and qualitative information is to be amassed for the analysis, even a major field research effort may be insufficient to uncover all aspects of sustainable livelihoods in a given site.' He suggests that the key for any intervention is '...to identify the institutional matrix which determines the major trade-offs (between, for example, types of 'capital', livelihood strategies and sustainable livelihood outcomes) for different groups of people and across a variety of sites and scales and so the variety of pathways available.' He also suggests that the use of his framework can '...act as a simple checklist of issues to explore, prompting investigators to pursue key connections and linkages between the various elements'. He ends the referenced paragraph with the rather lame observation 'While it offers no predictive power, it hopefully encourages the right sort of questions to be asked.'

Reardon (1997) reviews 23 field studies from sub-Saharan Africa concerned with household income diversification. His findings, which have been quoted in support of Ellis's work, provide an illuminating view of the importance of nonfarm, non-migration labour income in the rural household. He posits (p.739) that '...rural nonfarm activity tends to occur in the dry season...(because) own-produced crop stocks are often depleted...farm families thus buy food in the 'hungry season', the crop production period'. Farm families thus seek a source of off-farm income that is non-agricultural (as most agricultural labour is hired outside the dry season).

Reardon's data, being mean values from the aggregated results of many studies, are not particularly helpful in providing guidance for the relative contributions of such income sources in specific sites, such as the study herein. However, he draws some interesting conclusions from the reviewed data about the principal determinants of the differing relative contributions of income sources. He discusses these at the level of

both agroclimatic zone (analogous with the agro-ecological zones in Zimbabwe) and household.

For the level of agroclimatic zone determinants, he finds (p.741) ‘...a negative correlation between the level of the agroclimate...and share of income earned in migration by households in the zone.’ He also finds ‘...for favourable agroclimates – households tend to earn most nonfarm income locally, mainly in activities generated by production or expenditure linkages with the agricultural sector.’ In these favourable zones, he also observes that ‘...distribution of nonfarm earnings is more equal’ over households. These findings accord with the situation in Zimbabwe. The more productive areas (e.g. the northern part of the study district of Buhera) enjoy higher crop yields, with a more vibrant local economy and thus scope for local nonfarm income. The poorer agro-ecological zones (e.g. the southern part of the study district of Buhera) have lower yields and greater reliance on other sources of income.

For the level of the household, he finds four key determinants of participation in the rural nonfarm labour sector (p.742). Firstly, relative returns are better or own production is inadequate. This can either be a short term strategy to cope with a harvest failure or a long term strategy to manage risk, compensate for land constraints or take advantage of profitable opportunities. Secondly, off-farm income is used to pay for inputs, including hiring labour, where nonfarm wages exceed agricultural levels. Thirdly, households vary in their capacity to provide the ‘labour surplus’ to work off-farm. Larger families and those with ‘multiple conjugal units’ appeared to be more able to allocate the farm and home maintenance tasks to free up labour for work off-farm. Finally, education and skills are important, as are initial endowments of assets, which appear to provide the wherewithal to increase farm productivity and so release further labour and/or capital to establish off-farm businesses. Reardon noted that this gave rise, over the generations, to the domination of the local nonfarm sector by a subset of local families. Conversely, poorly endowed households are forced to focus upon the lower-pay, easier-entry farm labour market.

The UK’s Department for International Development has enthusiastically adopted the ‘sustainable livelihoods’ approach and has re-evaluated its sectoral strategies with this

in mind (Carney, 1998a). The referenced book was edited by Diana Carney and pulls together the key issues associated with the approach and the 'entry points' for the various sectors of rural development policy. It uses five asset categories (p.7): natural, social, human, physical and financial. (N.B. These are essentially the same as those listed by Ellis (2000) – see above – but with infrastructure and production equipment at household level, the physical capital, listed separately, whereas Ellis combines these assets in his 'Economic and Financial' category.)

Of particular interest to this work is Chapter 9 – 'Research and the Sustainable Livelihoods Approach', which sets out DFID's views on researching this topic (there is no named author). It is observed (p.132) 'At present, the Sustainable Rural Livelihoods approach exists as an hypothesis – that the integrated management of livelihood assets in rural areas is a universally applicable means of eliminating rural poverty. An important task for research is to test and subsequently transform the hypothesis into proven principles, which can, with confidence, be applied in practice.' It goes on to suggest alternative approaches to research: either '...rather limited, essentially focused on ex-post measurement of cause and effect followed by a series of iterations to adapt the emerging model to differing patterns of assets' or '...to improve understanding of the asset base and develop a suite of options from which choices can be made according to local circumstances, recognising that these may change from time to time.' The latter is clearly the preferred alternative of the writer, although there is some recognition of the need to examine how changes in the assets levels interact by recommending a systems-based approach to the analysis. The approach is summarised as follows: 'The Sustainable Rural Livelihoods approach will, therefore, require new knowledge of financial, social and human capital (social sciences), of natural capital (environmental sciences) and an understanding of physical capital (engineering sciences). It will also require an understanding of the variability within these capital assets and the interactions between them such that the potential effects of interventions on livelihoods can be predicted.' This clearly implies the development of some sort of over-arching model based on the livelihoods approach, but there is no further guidance as to how this might be formulated.

Two later works (Carney, 1999a) and (Ashley and Carney, 1999) compare DFID's approach to sustainable livelihoods with those of other donors and review early

experiences in applying the framework. It is clear from these reports that whilst there is some divergence between agencies about the form that any conceptual framework should take, they are in agreement that policy should address the full complement of household capital, rather than being directed at unilateral change of one particular asset category. This recognises the need to capture the interactions between assets. What is less clear, however, is the extent to which the various agencies are able to link such asset changes and interactions to the livelihood outcomes that are the objective of their aid programmes. In Ashley and Carney (*ibid.*), for example, the livelihoods monitoring system of CARE in Bangladesh is highlighted (p.28). This shows a series of ‘well-being’ indicators that ‘...are then used over time to track changes in the livelihood status of project participants.’ This may lead to the rather cynical view that the sustainable livelihoods approach, whilst taking a wider view of household capital, is at its heart an indicator-based methodology with little predictive power. Indeed, Ashley and Carney note (p.29) ‘Generic M&E questions, not specific to SL (Sustainable Livelihoods) – such as how to ascribe causality – also need to be addressed within the SL context.’

Despite this rather limited theoretical basis of the approach to analysing rural household livelihoods i.e. much of the reported work has focused on the need for the monitoring of assets, rather than developing a thorough systems analysis of household capital and activities, it seems appropriate to emphasise the benefits gained from this change of emphasis in looking at rural development. Carney’s briefing paper for the ODI (Carney, 1999b) puts this well. She notes (p.4), that in the past ‘Inadequate attention has been paid to the complexity of rural livelihoods and the multiple dimensions of rural poverty (their causes and effects)’, summarising the change as follows: ‘The new livelihoods approaches are attempting to address these problems by delinking the concepts ‘rural’ and ‘agricultural’ and widening the scope of rural development activity. They see sustainable poverty reduction as achievable only if external support works with people in a way that is congruent with their existing livelihood strategies and ability to adapt. This entails analysis of:

- the context in which (different groups of) rural people live, including the effects upon them of external trends (economic, technological, population growth etc.), shocks (whether natural or man-made) and seasonality;
- their access to physical, human, financial, natural and social assets and their ability to put these to productive use;
- the institutions, policies and organisations which shape their livelihoods; and
- the different strategies they adopt in pursuit of their goals.

The approach is non-sectoral. There is no implicit assumption that rural people are farmers, foresters or fisherfolk.'

These recent shifts towards a more inclusive view of the functioning of rural household economies is illustrated by comparing Ellis's (2000) espousal of a livelihoods approach with the focus of his previous works. The later previous work 'Agricultural policies in developing countries' (Ellis, 1992) reviews how policy deficiencies have arisen, but relates success or failure to whether interventions have bolstered agriculture, rather than any more general measure of improvement in rural livelihoods. Ellis hints at the need for a more holistic approach to the issue when discussing the research policy agenda, specifically 'Farming systems research' (p.232) and 'Farmer first research' (p.237), but never seems to make the leap from 'farm households' to 'households in which farming is practised', with all that the latter implies in terms of diversified activities. His earlier work, 'Peasant Economics' (Ellis, 1988), offers a review of farm household models anchored firmly in the neoclassical theories of farm production – from the outset (p.7) his focus is clear '...the definition of peasant is via its distinctive feature as a farm enterprise.' And again on p.8, '...for our main economic definition, peasant equals farmer.' He proceeds to develop and use the farm production function as a basis for comparing five theories of peasant economics: profit maximisation, risk aversion, drudgery aversion, farm household and share cropping (see his table on p.162). He notes that different communities will combine different attributes from more than one theory and observes (p.161) that '...these theories alongside each other ... emphasise the inseparability of household behaviour from the larger social system.' Although he returns to this theme of variability amongst peasants (and amongst the resource and

output markets), he still focuses on agriculture as the principal issue, concluding (p.241) ‘the failure of agricultural policy to take into account local variation in social relations frequently results in waste of resources and unintended side effects.’

It is clear from the literature that many authors in the late 1980’s and early 1990’s also exhibited a strong agricultural focus to household economic models. Typical of these is ‘Agricultural Household Models’ (Singh et al., 1986a). Contributions to this book include both theoretical analyses and case studies. The basic model covers the production of a single staple as a subsistence crop, within a household that is a price-taker for the staple itself, for a marketed commodity and for labour. This model is extended by contributing authors to cover multi-crop production, the links to food consumption, labour allocation behaviour and the functioning of markets. Various case studies are presented by the contributors for developing countries in Africa, India, China and south-east Asia. In the basic model, Singh et al. (1986b) provide a comprehensive analysis of the behaviour of agricultural households, by developing a series of models to represent the simplified, but most important aspects of economic behaviour. They draw the distinction between classical theories of behaviour of consumer households that predict that price increases will reduce demand (due to substitution and income effects) with their own models that show that agricultural households act as both consumers and producers (so mitigating the income effects through profit increases from sale of own production). The analysis is continued with the assessment of the models using input data from several developing countries to predict changes in key indicators of food prices, labour rates and calories consumption.

The basic model of Singh et al. (ibid., pp.17,18) is essentially a distillation of earlier work in the development of such models and underlies most of the case studies carried out previously by others.

Singh et al. assume that for any production cycle, the household will maximise a utility function:

$$U = U(X_c, X_m, X_l) \quad \text{----- Equation 1}$$

Where the commodities are:

X_a an agricultural staple, X_m a market-purchased good and X_l leisure

Utility is maximised subject to an income constraint:

$$p_m X_m = p_a(Q - X_a) - w(L - F)$$

where p_m and p_a are the prices of the market-purchased commodity and the staple respectively. Q is the household's production of the staple (so that $Q - X_a$ is its marketed surplus), w is the market wage, L is the total labour input and F is family labour input (so that $L - F$, if positive, is hired labour and, if negative, is off-farm labour supply).

There is a time constraint upon the household:

$$X_l + F = T$$

where T is the total stock of household time.

There is also a production constraint that depicts the relation between inputs and outputs:

$$Q = Q(L, A)$$

where A is the household's fixed quantity of land.

Singh et al. collapse the three constraints into a single constraint, to give:

$$p_m X_m + p_a X_a + w X_l = wT + \pi \quad \text{-----} \quad \text{Equation 2}$$

where $\pi = p_a Q(L, A)$ and is a measure of farm profits.

The left-hand side of this equation shows total household ‘expenditure’ on three items – the market-purchased commodity, the household’s ‘purchase’ of its own production and leisure (which can be thought of as the household’s ‘purchase’ of its own time). The right-hand side extends the concept of full income in the household production models of Becker (1965). To the value of the household’s stock of time (wT) is added a measure of farm profits, with all labour valued at market wage, this being a consequence of the household being a price-taker in all markets.

Equations 1 and 2 are the core of all the models developed in the remainder of the book and form the basis of the case studies and simulations presented.

Potentially such models might offer useful tools for the modelling of a local food system. Two contributors to Singh’s book, Smith and Strauss (1986) apply a micro-simulation to rural households in Sierra Leone. They note (p.206) that in comparison to policy models that use point elasticities of representative households to estimate the behavioural effects of exogenous price changes, ‘micro-simulation...may be preferred for several reasons. First, this method takes full account of nonlinearities in the model and the fact each household faces a different set of independent variables and that therefore response elasticities vary among households. ...Second, several prices can be varied at once...an important advantage when examining general equilibrium effects. And finally, micro-simulation is ideally suited for analysing the distribution effects of economic policies, especially when the simulation is at the level of individual household.’ However, Smith and Strauss report only limited success with the simulation, noting (p.210) that other than for rice, predicted per capita production did not accord well with observed values. Estimates of the mean marketed surplus, for most crops (except rice) and all livestock, showed large deviations from observed data. The simulation also performed poorly in capturing the behaviour of different

expenditure groups, although reportedly was more successful for the whole population.

This apparent failure of Smith and Strauss's micro-simulation may in part be attributable to the exclusion of inter-household transactions, other than those modelled indirectly through market mechanisms. More recent approaches to simulation have stressed the need to capture such transactions within the framework of the model. A recent book by Taylor and Adelman (1996) concerns village economies and the need to analyse the relationships and transactions of the community, both inside the village (inter-household relationships) and between the village and institutions outwith the village at regional or national level. They review the various economic modelling approaches to deal with the impacts of policy changes upon rural economies. They suggest that these have mainly followed two paths: microeconomic household-farm models and village social accounting matrix (S.A.M.) multiplier models. Taylor and Adelman propose a village-level computable general-equilibrium model (C.G.E.), 'Micro-C.G.E.', to occupy the middle ground between household-farm models and aggregate C.G.E. models used for national policy analysis. In their review of household-farm models, they point out that whilst these models represent the dual character of households as producers and consumers interacting with regional markets for outputs, inputs and consumption they fail to examine the interaction among households. Their critique contains an example whereby, under a household-farm model, a price support policy for staples would stimulate an increase in marketed surplus. They note however that income linkages and local general-equilibrium feedback within the local economy may dampen or even reverse this modelled increase. The increased consumption expenditures of the staple producing households includes a substantial element of demand from their nonstaple-producing neighbours for nontradable goods and factors, some of which are inputs to staple production itself. This dampens the staple-supply response. Furthermore, where such nonstaples are less elastic than the staples themselves, this brings about an income increase for the nonstaple-producing households, boosting demand for staples within the village as a whole. Thus the price support policy may bring about reduced availability of staples to consumers outwith the village, rather than the increase suggested by household-farm modelling approaches. Taylor further

argues that policies and other exogenous changes, even those not directly affecting marketed surplus or agricultural production, such as migrant remittances, will also have indirect effects as their impacts work their way through the households within the village. Taylor (1995) describes this in more detail with reference to Mexican household-farmers.

A different approach to household-farm models has been reported recently by Bright (1999). He analyses inter-temporal household-farm liquidity using an accounting model to represent cash and asset stocks and flows. His model encompasses 60 months, based on other authors' data for the principal characteristics of a household in Kordofan, Sudan. Agriculture in this modelled household is limited to a simple generic grain, with no livestock and all other income and assets are of fixed value, save for seasonal migrant remittances. Using actual agriculture performance data for the period modelled (1988-92), Bright demonstrates that despite the availability of credit, resource poor households are very vulnerable to a series of shocks such as the harvest failures that occurred in the Kordofan area in 1990, 1991 and 1992. He also shows that fertiliser uptake by subsistence farmers is likely to exacerbate liquidity problems in fragile agro-environmental conditions unless optimistic yield improvements are realised. This finding is consistent with Oglethorpe's (1995) analysis referred to in the next section.

A particular difficulty with household-farm models is the use of the household as the basic unit of economic decision making. Anthropologists (Yanagisako 1979) make reference to the complexity and flexibility of household structures and to the diverse influences within the village upon inter-household relationships. In many parts of Zimbabwe, polygamy is practised. How should polygamous households be treated: as one unit, male-headed with many wives and children or as separate female-headed units with an external income source? This is discussed further in section 3.4.

To overcome problems with household-farm models, the S.A.M. approach was developed to reconcile national income and product accounts with input-output analysis (Stone, 1978) and first applied to village economies by Adelman et al. (1988). It takes the form of a double entry framework, analogous to the fundamental method of recording transactions as debits/credits in financial accounting, see Dyson

In a S.A.M., as in an accounting system, equality is maintained between the sum of incomes and the sum of expenditures. However, the S.A.M. allows an individual 'rest-of-world' institution to be out of balance, provided that the aggregate position remains in balance. Linkages between institutions within the village and to the 'rest-of-world' are explicitly recognised in village S.A.M. multiplier models. Taylor and Adelman (1996) note three limitations to this modelling approach: the absence of prices, the perfect elasticity of supply and the linear response of production to factor inputs. They develop a village C.G.E. model to overcome these limitations, retaining the consistency of the double entry approach used in S.A.M.s, but introducing non-linearities into the model for production inputs and constraining the availability of resources for village production. They also implement price mechanisms, albeit that most prices are assumed to be exogenously determined as all the villages selected for study are considered to be well integrated into regional markets. These simulation experiments provide ample support for the complexity of village economies. Taylor and Adelman comment (p. 249): 'Researchers who ignore the diversity of village economies and village institutions can easily misrepresent the impacts of agricultural price policies on rural production, incomes, marketed surplus and other variables of interest'.

Whilst accepting the contribution of Taylor and Adelman's work to the modelling of villages, there seem to be three obstacles to the use of their approach to model the food system in Buhera. Firstly, the focus of the S.A.M. and C.G.E. models is the economic analysis of villages rather than the nutritional status of the populations therein. Although Ralston (1996) incorporates nutritional status into a S.A.M. for an Indonesian village, this is achieved by classifying households by daily calorie consumption and treating the three resultant groups as separate institutions within the village. The resultant analysis remains primarily economic rather than dealing explicitly with nutritional issues. Secondly, Taylor and Adelman accept in their concluding remarks (p. 252) that geographical scope is sacrificed in favour of local economic detail and that the modelling approach is limited in application to using primary surveys to collect the particular data required for such models. Secondary data do not support these types of approach. Thirdly, the modelling approaches are essentially concerned with annual, aggregate economic analyses rather than any shorter time periods, as would be required to take account of seasonal variability in

household resources and the impact of same upon nutrition within the household. Before leaving Taylor and Adelman, their penultimate sentence (p.253) should be noted: 'As rural economies become more complex and villages become increasingly integrated with outside markets, new insights can be gained by linking villages and towns together into regional C.G.E.s as a basis for understanding the implications of economic integration for rural economies'.

2.4 Environmental risk and coping strategies

In their wide ranging review of the impacts upon nutrition of agricultural development and its commercialisation, von Braun and Kennedy (1994) observe (p. 4):

'Subsistence agriculture is chosen by farmers because it is subjectively the best option, given all constraints'. They note that 440 million people worldwide still practise subsistence production and although a large proportion of land in low-income countries is devoted to it, it is becoming increasingly less viable as the constraints and degradation of natural resources and the urbanisation of the developing countries all increase.

Most subsistence farming in southern Africa occurs on semi-arid lands characterised by poor soils and low levels of rainfall, the latter being variable in both quantity and temporal distribution from year to year. To minimise the exposure to these environmental risks, subsistence households have evolved coping strategies. These combine farming systems which are low input (reducing the loss in the event of failure) and partially diversified (with a portfolio of food and cash crops each having a different rainfall profile) with off-farm sources of food and income. Interestingly, this strategy of reduced intensity and diversification under variable environmental conditions is in agreement with the conclusions reached by Oglethorpe (1995) in his formal analysis of risks facing European farmers exposed to market price instabilities. As Oglethorpe concludes '...a risk averse farmer, who adopts a utility maximising farm plan, will produce a level of intensity significantly lower than that which would be adopted under profit maximisation. Moreover, with only minor reductions in expected income, at sub-optimal profit levels, the farmer can greatly reduce income variance.' In developing countries, Peters and Herrera (1994) report that the agricultural subsistence ratio (share of household agricultural production directed

towards household's own consumption) is higher for poorer households, smaller landholdings and non-cashcrop growers. Interestingly, they also report that the highest ratio is for the middle two income quartiles and not the poorest quartile. This accords well with observations in Zimbabwe (Corbett, 1994) that the poorest households tend to sell staples soon after harvest to meet pressing cash needs although the total harvest is below the household's expected requirement for the coming year.

Reactions by households to food shortages cause an evolution of 'food strategies' or 'coping strategies', which are summarised by de Walt (1983) as:

- Foraging;
- Home production;
- Income diversification to purchase foods;
- Gifts;
- Adjustments to consumption behaviour;
- Adjustments in household composition.

In terms of Sen's entitlement approach, it could be said that without adequate coping strategies, the poor harvests and fragmentary marketing channels would erode a household's 'endowment bundles' by the combined failure of its production and trade entitlements.

Messer (1989) provides a broad review of each of these coping strategies, emphasising their widespread adoption in developing countries. Daniel Maxwell (1996) demonstrates that by observing the frequency and severity of the different coping strategies practised by households, it is possible to construct an index of food insecurity that correlates well with other measures. The diversities of coping strategies adopted by households in Zimbabwe have been described by Corbett (1988) with interest focused on the uptake of these strategies over time (based on the work of Longhurst (1986)). Remittance income forms an important proportion of total household income in most communal areas of Zimbabwe and in the most marginal agricultural areas, such income is the mainstay of food access (Corbett, 1994). There

is evidence from Botswana that level of remittances is inversely correlated with harvest performance (Valentine, 1993). Davies (1993) notes that the diversity of coping strategies by which the rural poor adapt to vulnerability and how they act in times of nutritional stress has emphasised the need for researchers to recognise the individuality of livelihood systems. This emphasis upon individuality implies that micro-level, rather than aggregate analysis of communities and their coping strategies may offer an improved understanding of the complex processes within local food systems.

Several more recent papers have suggested that risk, especially longer term risks to livelihoods, should be placed in the context of the different levels of society, each of which has a role to play in 'Social Risk Management'.

Siegel and Alwang (1999) draw a distinction between covariate risks, that simultaneously affect many households in a community or region, e.g. droughts and idiosyncratic risks that are household specific in their timing e.g. AIDS. They suggest that the impacts of idiosyncratic risk can be mitigated through informal insurance mechanisms, based on social ties and networks. However, because of the confined nature of the 'risk pool' (and the poorly functioning or missing insurance and credit markets) household risk management strategies can be inefficient with consequential negative implications for social welfare. They propose a conceptual framework of 'Social Risk Management', which adopts an asset-based approach.

There are parallels here to the work on livelihoods by Carney, Scoones and Ellis, reviewed in the previous section, as evidenced by the categorisation of assets laid out in the multi-level analysis presented in Figure 2.4 below (Siegel and Alwang, *ibid.*, p.11).

Asset Type	Household (HH) Level	Community Level	Extra-Community Level
Natural	"Private" land, pasture, forests, fisheries, water: quality and quantity	"Common" land, pasture, forests, fisheries, water	National and Global commons, rivers and watersheds, lakes, seas, oceans, air
Human	HH composition and size Health and nutritional status Education and skills	Labor pool	Labor markets
Physical	Productive assets (tools, equipment, work animals) Household assets (e.g. housing, household goods and utensils) Stocks (e.g., livestock, food, jewelry)	Productive assets (communal and private) Stocks (e.g., livestock, food)	Productive assets (rental markets) Stocks (e.g., buffer stocks)
Financial	Cash, savings, access to credit, and insurance markets	Cash, savings, access to credit and insurance markets	Finance and insurance systems Access to international finance
Social	HH social ties and networks Intra-household dynamics	Community social ties and networks	Extra-community social ties and networks
Location and Infrastructure	Proximity and access to water and sanitation, education and health, marketplace, storage, roads	Water and sanitation, schools, health centers, marketplace, storage facilities, roads Proximity to transport and communication infrastructure	Distance to markets, transportation, communication, information systems Health and education infrastructure
Political and Institutional	Participation in household decisionmaking (including power relationships related to gender and age)	Participation in community decision-making Governance Security of person and property	Political stability Political participation Effectiveness of collective action Governance Human rights and security of person and property

Figure 2.4 Household-level assets and links to other levels. (from Siegel and Alwang, 1999)

As Siegel and Alwang note (p.12), the list of assets shown above is rather long, perhaps giving a false impression of the 'wealth' available to households. The extant position of most sub-Saharan rural households is that they are asset-poor and that the levels above (i.e. community and extra-community) are also poorly endowed, being spatially isolated, with poor infrastructure and limited political 'clout'.

They also discuss attitudes towards risk and the impact that these have upon the management objectives set by the households themselves. They note (p.14) the following important features of such attitudes:

- **Link between production and consumption** – ‘...because the primary objective of rural households is often food-self-sufficiency...(with) concerns about food price risk...exacerbated by poorly functioning markets...they choose to produce more low value crops.’
- **Risk attitudes are difficult to infer** – ‘studies...tend to attribute all inefficiencies to risk aversion’ and overstate the influence upon management objectives, when other constraints may be the cause.
- **Numerous constraints and missing markets** – wealthier households have access to better insurance/credit markets; female-headed households are discriminated against, for example, by agricultural support practices.
- **Value systems affected by struggle for survival** – time horizons and discount rates are affected by conditions of extreme poverty and destitution. Perceptions of good/bad, legal/illegal and ethical/unethical will change and so change the attitude to risk.
- **Murphy’s law** – faced with continual difficulties, households base risk perception on ‘anything that could go wrong, will do’ rather than an objective assessment.

Siegel and Alwang (ibid.) discuss at some length the instruments that are available to households to manage risk, summarised in Figure 2.5 below, based on earlier work by Holzmann and Jorgensen (1999), Bendokat and Tovo (1999) and the World Bank (1999).

	Household Level	Community Level	Extra-Community Level
Risk Reduction			
	Investment to protect, maintain and enhance assets Adopt new technology Adjust asset portfolio and income-generating activities Permanent migration	Investments in physical and social infrastructure Social ties and network Participation in community institutions and decision-making Rules and regulations Rights and security	Information on risk and risk reduction Rules and regulations Guaranteed rights and security Stable macro-economy, policy regime, and political system Open and free markets Responsive institutions Investments in public goods, physical and social infrastructure
Risk Mitigation			
Asset portfolio Management	Adjust asset portfolio and income-generating activities Hold financial or non-financial assets (e.g., livestock, food stocks) for precautionary savings Seasonal migration	Markets for household assets Physical and social infrastructure	Markets for household assets Market information Investments in physical and social infrastructure
Insurance	Formal insurance Informal insurance based on intra-household social capital claims Inter-linked contracts	Informal insurance based on community social capital claims Formal community insurance pooling associations	Formal insurance, private and public sector, and international organizations (e.g., crop insurance, health insurance) Disaster aid funds
Finance	Formal and informal credit Inter-linked contracts	Community credit unions and savings clubs, and "banks" for other asset stocks	Financial systems, national and international Inter-community credit associations and "banks" for other stocks
Risk Coping			
	Draw down assets (e.g., skip meals, mine soil, not pay school fees) Use underemployed assets (e.g., off-farm employment, child labor) Sell assets Encroach on assets of others Illegal activities Formal and informal credit Depend on charity	Draw down community assets (e.g., reduce maintenance, harvest or mine natural resources) Depend on charity or aid from outside community	Targeted safety nets (transfers, public works) Social investment projects (e.g., social funds) Depend on charity or aid from national or international organizations International food aid Donor assistance

Figure 2.5 Instruments available to households to manage risk (Siegel and Alwang, 1999)

A later paper by Holzmann and Jorgensen (2000) takes the concept of Social Risk Management and suggests that it can be expanded to offer a framework for 'Social Protection'. They observe that welfare is enhanced by good social risk management, in a static setting, in three ways: reduced vulnerability, enhanced consumption

smoothing and improved equity. However, they point out that inappropriate instruments can perpetuate or deepen poverty (in a similar way to those set out by Siegel and Alwang (see above)). One particularly interesting observation is that the high costs associated with informal risk sharing through social ties and exchange of gifts often exclude those in most need of such arrangements. These ties provide mutual insurance for idiosyncratic risks, based on a principle of balanced reciprocity. But, the arrangements often exclude the very poor as they are unable to offer counter-gifts and/or are reluctant to engage in exchanges where the initial commitment is a major share of household income. Such informal reciprocity also tends to break down in cases of large idiosyncratic and covariate risks.

Holzmann and Jorgensen (*ibid.*) also note (p.8) the importance of effective social risk management upon transitory poverty. They provide a summary of panel data for six developing countries, plus Russia and China, as shown in Figure 2.6 below.

		Percentage of Households who are:		
		Always poor	Sometimes poor	Never poor
China	1985-1990	6.2	47.8	46.0
Côte d'Ivoire	1987-1988	25.0	22.0	53.0
Ethiopia	1994-1997	24.8	30.1	45.1
Pakistan	1986-1991	3.0	55.3	41.7
Russia	1992-1993	12.6	30.2	57.2
South Africa	1993-1998	22.7	31.5	45.8
Vietnam	1992/93-97/98	28.7	32.1	39.2
Zimbabwe	1992/93-1995/96	10.6	59.6	29.8

Source: Baulch and Hoddinott, 1999 and Vietnam Draft Poverty Report, 1999.

Figure 2.6 Mobility into and out of poverty for selected countries (Holzmann and Jorgensen, 2000).

Although there is much, rather vague, discussion in Holzmann and Jorgensen's paper about the theory and conceptualisation of Social Protection and Social Risk Management, the authors provide (p.25) some useful 'guiding principles' suggested by their theories:

- **Espousing a holistic view** – greater interrelation between issues and options, and between stakeholders and institutions, plus improved data and analytical techniques that draw upon the target countries, NGO's and donors.
- **Balancing coping, mitigation and risk reduction strategies** – whilst risk avoidance is clearly the preferred option if costs (both opportunity and direct) are ignored, the optimal strategy will be to balance risk-reducing measures with coping and mitigation actions.
- **Building on comparative advantage of actors** – because of the asymmetric nature of information and instruments available to the various actors, increasing institutional involvement in risk reduction, but withdrawing from risk mitigation, other than as regulator (leaving the private sector to carry out this role) may be a more appropriate future role for government. However, this should be coupled with coping interventions for the incapacitated and most vulnerable.
- **Matching interventions and risks** – government and international interventions are entirely appropriate for major risks that individuals, households and communities are poorly equipped to handle. For less catastrophic risks, informal and market-based interventions will be more appropriate, but regulated by government.

Much of this section has dealt with the longer-term risk strategies of households, communities and extra-community institutions, wherein people's livelihoods and very existences are threatened by exogenous shocks over an extended period. Obviously, there are much shorter term (even day-to-day) risks that impact upon rural subsistence households. Where such households' activity includes a substantial portion of agricultural production or their income sources are related to agriculture, directly or indirectly, then seasonality will have an important impact. This is dealt with in the next section.

2.5 Seasonality

The previous section dealt with the year-to-year environmental risks facing subsistence households and their coping strategies. The impacts of shorter term environmental changes within one season are reviewed herein.

Rural economies are reliant on rain-fed agriculture for the substantial part of the food supply to households, either by consumption of own produce or by sale of cash crops and purchase of staples from other households or local traders. Thus, although remittances from migrant workers and other non-agricultural off-farm earnings form important contributions to household income, agricultural performance remains an important determinant of most households' 'food security'. Rukuni and Jayne (1995) observe (p.41) that in Zimbabwe '...one of the most direct ways of increasing their (i.e. rural households') real income is to increase the productivity of their main enterprise, maize production.' Much of the literature referenced above is concerned with the economic analysis of subsistence farming over many years or the analysis of the aggregate position at the end of one agricultural season. However, this work is directed towards the modelling of intra-seasonal variability in the food system and the resultant nutritional changes that occur. Before examining the core concepts of 'food security' and the other non-food influences upon nutritional change, a summary review of seasonality will be presented.

The effects of the seasonal variability in agriculture upon food security are discussed at some length in an earlier work edited by Sahn (1989). In this collection of papers, various contributors emphasise the multiple consequences and determinants of seasonal malnutrition.

Messer (1989) takes an anthropological perspective, summarising the broader socio-cultural aspects (p. 151): 'Seasonality enters into all dimensions of food systems - patterns of food acquisition, cultural preferences, rules for social distribution, and consumption - and their evolution. The sources and symptoms of seasonal food insecurity have been noted both in general ethnographic studies and in more specialised studies of food, nutrition, and health. While foragers (hunters and gatherers), herders (who move according to the seasonal availability of water and

food), and agriculturalists (who plant and harvest according to the seasons) are touched most directly by the calendars of temperature and rains, those relying for their livelihood on crafts, trade, and industry may also suffer seasonal food insecurity due to periodicity in their incomes, in affordable food supplies, or in both.' Messer's work discusses the way in which societal factors evolve in response to the uncertainties in the food system, to dampen the impact of any one event. These societal factors can be thought of as long term, slowly changing variables, which modulate the direct impacts of food shortages in any one season.

Payne (1989) notes (p.45): 'As far as children are concerned, the most important features of seasonal effects will be those that operate through the nutrition-infection interrelationship. The climatic aspects of infectious disease transmission, particularly for those conditions that adversely affect young children, have been reviewed in detail by Chambers et al. (1981).' This emphasises the importance of considering non-food factors in modelling the food system, where the objective is to estimate changes in nutritional status amongst members of a community.

Not only do food access and infection exhibit seasonal variability, but in an agriculturally based society, labour requirements will also vary depending upon the cultivation and husbandry tasks required at any given time of the year. This mainly affects adults. Men usually plant the crops at the onset of the rainy season, women carry out the weeding and hoeing during the growing season and men supervise the harvest by all family members at the end of the season. Where men are resident for the whole year, this will involve switching from other farm tasks or off-farm activities, increasing their daily energy requirements with the more intense tasks. Where the men are migrant workers, it is common for employers to allow workers home for the two high-activity agricultural periods, albeit on unpaid leave. Although these households will benefit from an increase in labour resources, they will have an increase in aggregate energy requirements from the men returning home and will also have reduced income for the period. Women's labour also shows seasonality, with Lawrence et al. (1989) reporting peak levels of energy expenditure for adult women in Gambia occurring immediately prior to, and at the start of, the rainy season as shown in figure 2.7 below.

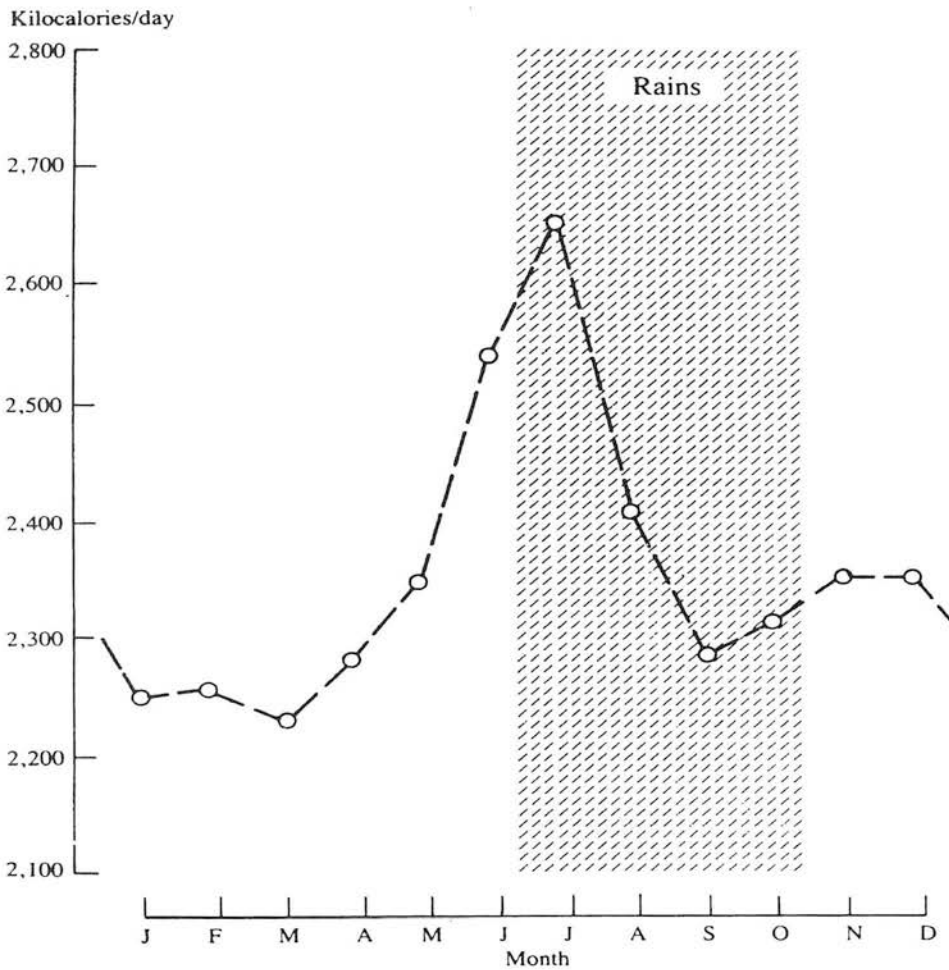


Figure 2.7 Seasonal variation in total energy expenditure by rural Gambian women, adjusted for stage of pregnancy or lactation. (Lawrence et al (1989), in Sahn (1989)).

Seasonality also affects market prices for staples. Sahn and Delgado (1989) report numerous examples of wide seasonal variability in market prices. Delgado's study of Nigerian market prices over several years (Delgado 1986) suggests that pure seasonal effects may amount to 25-33% compared to the mean food price, although this element may account for less than 25% of the observed variations in a nine year period. Sahn and Delgado discuss the extent to which intertemporal price equilibrium models can explain the variations in prices. From a review of several authors' works they conclude that high levels of post-harvest losses and the costs of storage can indeed explain the high seasonal variability observed. With reference to a modified theory of intertemporal price equilibrium, incorporating uncertainty, developed by Working (1958) and expanded by Goldman (1974) and Boius (1983), they comment

(p. 188): 'Its major contribution is that seasonal fluctuations in prices are not solely attributable either to current supply and demand forces bringing about an equilibrium price, to which the storage costs are added over time, or to a single forecast of future conditions. Rather, expectations concerning supply and demand conditions in the future are constantly being revised during the year. Prices fluctuate from month to month in response to changing anticipations of supply and demand forces. Thus seasonal price spreads may differ markedly from year to year as anticipations differ.' Such anticipatory behaviour occurs in Zimbabwe. Typically farmers will sell a proportion of harvest foodcrops immediately after harvest, retaining the remainder for own consumption based on household requirements for a forward period in excess of one year. Once the outcome of the current year's harvest becomes predictable, the portion of the previous harvest held in store for insurance against a poor outturn is sold. In good years, Zimbabwe's parastatal Grain Marketing Board sees a surge in receipts around January-February, when the rainy season is well underway and the staple crops have passed the critical points in their growth cycles. Sahn and Delgado conclude (p. 194): 'Expectations of future, more than present, grain supply and demand conditions have major impact on storage behaviour, and thus on seasonal price variation. Incorrect expectations lead to supply and demand imbalances in the future, which contribute to the erratic pattern of seasonal price increases.'

2.6 Food security

In Maxwell's (1996) post-modern perspective, he describes (p.155) food security as being '...a cornucopia of ideas' and welcomes the change from a single definition to a more complex and diverse concept, observing that this is more in line with the perceptions of the food insecure themselves. This paper builds on an earlier work in which Maxwell and Smith (1992) review the concept of food security. They trace the history of food security policy from the Universal Declaration of Human Rights in 1948, to the world food crisis of 1972-74 and to the impact on donors, international agencies and the general public of the African famine of 1984-85. They note that since the 1970's there has been a focal shift from international and national food security, with aggregate measures of food availability, to an individual and household level of analysis, with greater emphasis on access, entitlements and vulnerability.

Maxwell and Smith suggest that the core concepts of food security are:

- **Sufficiency** – In taking the generally accepted daily requirements shown in section 1.3, viz. 2,500 kilocalories for a man, 2,200 kilocalories for a woman and 1,500 kilocalories for a child, researchers are usually concerned with the quantitative issues relating to food sufficiency of the individual (cf. household), rather than qualitative issues of protein and micronutrient content. (To some extent, this is a view from the 1970's, when nutritionists contended that quantitative sufficiency also produced qualitative sufficiency (Joy, 1973). However, some international agencies are now taking greater account of specific micronutrient deficiencies with a view to targeting affected populations with low-cost dietary supplements (A.C.C./S.C.N., 1991).)
- **Access and entitlements** – Individuals (and households) have adequate food access if they have an entitlement set which includes a commodity bundle with an adequate amount of food. This entitlement set is determined by what an individual (or household) can produce, trade, inherit or receive by gift. This is in line with the work of Sen (1981), reviewed earlier in this chapter.
- **Security** – Individuals (and households) are food insecure if they 'have an undue risk of losing access to the food needed for a healthy life' (A.C.C./S.C.N., 1987). Maxwell and Frankenberger (1992) observe (p. 14) that a distinction is useful 'between the risks of entitlement failure and the costs borne in the event of failure'. Policy can then focus on either 'entitlement promotion or protection' (Drèze and Sen, 1989).
- **Time** – The concept of security emphasises the time dimension to food access. The World Bank (1986) differentiates between chronic and transitory food insecurity. Maxwell and Smith (1992) write (p. 15): 'Chronic food insecurity means that a household runs a continually high risk of inability to meet the food needs of household members. In contrast, transitory food insecurity occurs when a household faces a temporary decline in the security of its entitlement and the risk of failure to meet food needs is of short duration. Transitory food insecurity focuses on intra- and inter-annual variations in household food access. It has been argued that this category can be further divided into cyclical and temporary food insecurity. Temporary food insecurity occurs for a limited

time because of unforeseen and unpredictable circumstances; cyclical or seasonal food insecurity when there is a regular pattern in the periodicity of inadequate access to food. This may be due to logistical difficulties or prohibitive costs in storing food or borrowing.'

These core concepts refer to the processes underlying the attainment or otherwise of food security for an individual (or household). They omit the physiological outcomes associated with under-nutrition and the interaction of these outcomes with the processes of infection and care. 'Nutritional security' may be a more comprehensive and appropriate term to encompass these issues. The choice of phrase 'food' or 'nutritional' security was the subject of much debate at a workshop a United Nations meeting on Household Food Security, attended by the author in Rome in 1995. The agencies represented included World Food Programme, Food and Agriculture Organisation, IFPRI, UNICEF and IFAD. There was no consensus as to the preferred phrase, but many felt that 'nutritional security' provided extra emphasis on the need to consider aspects other than the simple consumption of calories i.e the need for micro-nutrients and the interaction with disease. It was accepted that inadequate dietary intake alone could be a possible cause of malnutrition and that disease alone could be an independent pathway to reduced nutritional status (e.g. cancer, AIDS). But, in the former case, the individual would become malnourished and the weakened physical state would expose him/her to greater risk of infection. Similarly, in the latter case, the individual would suffer from infection or illness, but any reduction in his/her nutritional status would be brought about by the impact of the disease upon the dietary functions and consequential reduced absorption of calories. This view is reinforced by the United Nations Sub-Committee on Nutrition publication 'Nutrition and Poverty' (A.C.C./S.C.N., 1997) where in the overview (p.17) it is stated 'Nutrition is more than food. Health, care and a health environment are equally necessary for good nutrition. The food basket approach to estimate poverty should be re-considered. Moreover, food is not merely an aggregation of calories – micronutrients are important components which need more attention.'

2.7 The 'malnutrition-infection complex'

Several authors (Lindskog et al., 1988; Scrimshaw and Taylor, 1968; Kambarami et al., 1991) report that with reduced levels of food access, the decline in nutritional status amongst household members can result in a lowering of resistance to infection and/or an increase in both severity and duration of illness. Outbreaks of disease occur where the lack of adequate potable water supplies and household sanitation provide an appropriate environment for the infection vector to propagate. Illness reduces the ability to consume food and to work, so eroding nutritional status still further. This downwards spiral of interaction, the 'malnutrition-infection complex', is cited as the most prevalent public health problem in the world today (Tomkins et al., 1989). Rudimentary health and social services, in many countries reduced further by cutbacks under Structural Adjustment Programmes, generally fall short of the target levels suggested by the World Health Organisation and do not provide the necessary treatment or education to combat infection.

Several papers concerned with nutritional (cf. food) security (Cutler, 1984a, 1984b and 1985; Shoham and Clay, 1989; Borton and Shoham, 1991) give prominence to impacts of factors other than food supply in determining the malnutrition rates. The gradual shift away from a supply side analysis of nutritional security is summed up by Maxwell and Smith (1992) who note that (p24) 'food security, health and care are each necessary but none sufficient on its own for adequate nutritional security'.

In 1990, the United Nations Children's Fund (UNICEF) (1990) proposed a causative model of the 'malnutrition-infection complex' that has gained widespread acceptance (Gillespie and Mason, 1991). This model is reproduced in figure 2.8 below. Maxwell and Frankenberger (1992) discuss a slightly modified version of this diagram that shows 'inadequate dietary intake' and 'disease' within the same box on the diagram, rather than as two separated boxes shown in the text of the thesis. They note (p.24) 'It implies that household food security is necessary but not sufficient for adequate nutrition; and, in turn, that growth faltering cannot necessarily be ascribed to a failure of household food security. From this, it is said that to follow a deterioration in anthropometric indicators cannot be interpreted on its own as identifying a decline in food intake, let alone in food security.'

It will be seen from this diagram that the immediate causes of malnutrition are inadequate dietary intake and disease, which are shown to interact. The underlying causes are an insufficient level of food security, inadequate care both in the home (maternal and child care) and institutionally (insufficient health services) and an unhealthy environment which facilitates the spread of disease. Below these, the model shows various 'basic causes' linked to socio-economic structures. One aspect of the UNICEF causative model is the lack of a time dimension to the variables shown. As noted in section 1.3 above, malnutrition can be chronic or transitory (with the latter split between cyclical and temporary events). Some causes in the UNICEF model, such as dietary intake, household food security and disease will probably exhibit short-term variability whereas care and environmental factors are likely to change more slowly over time.

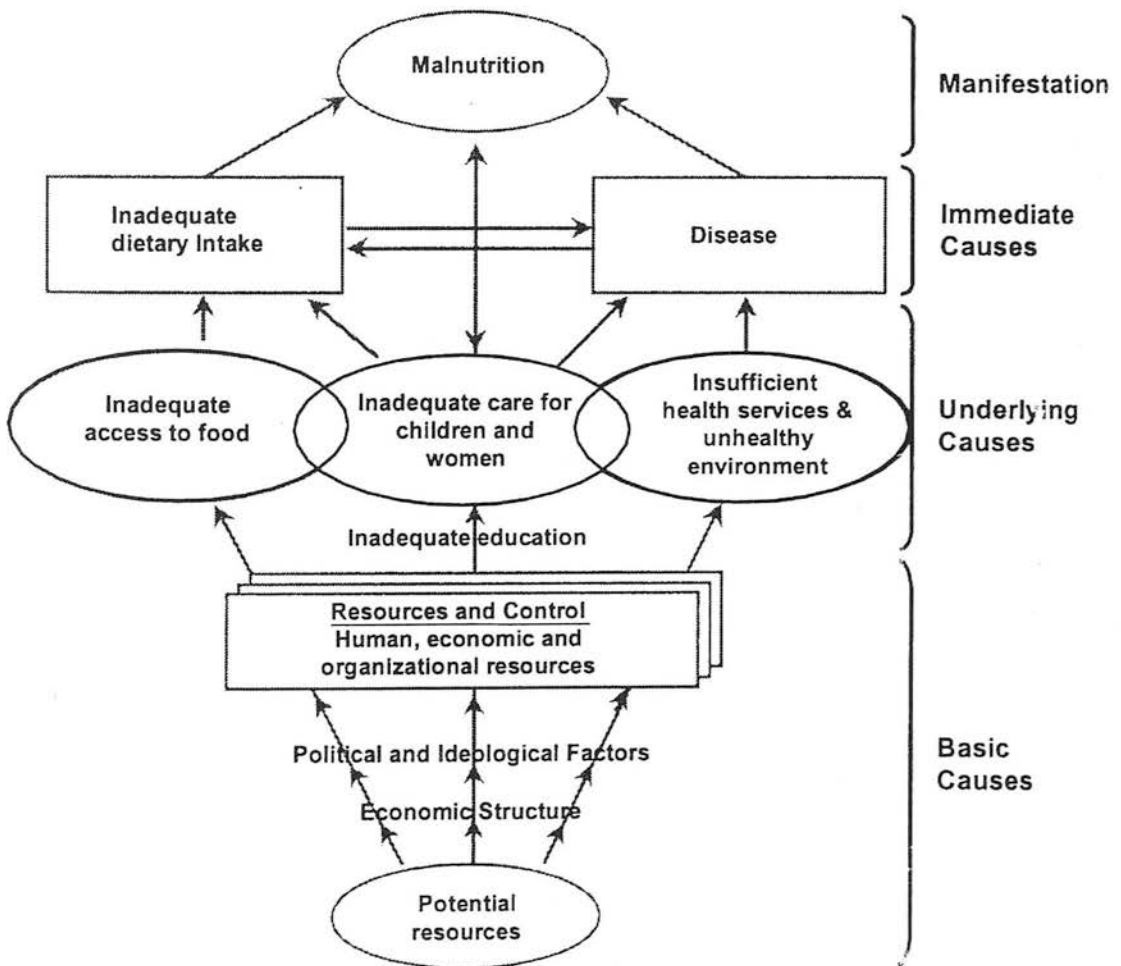


Figure 2.8 UNICEF diagram of the 'malnutrition-infection complex'

There are numerous examples of care and environmental factors, at household and community level, which appear to correlate with nutritional status: potable water supplies (Lindskog et al., 1988), sanitation (UNICEF, 1991), access to health services (Rosensweig and Wolpin, 1982; UNICEF, *ibid.*), level of education of household head (Horton, 1988; Senauer, 1990; Mazur and Sanders, 1988), gender of household head (Trip, 1982; Kennedy and Peters, 1992; Alderman et al., 1995), dependency ratio (Mazur and Sanders, *ibid.*; Ferro-Luzzi et al., 1992), spacing of children's births (Horton, *ibid.*) and weaning practices (Moy et al., 1991).

However, although the referenced findings illuminate the complex linkages that contribute to the physiological processes determining nutritional status, they are limited in their assessment of the interaction between factors. As presented in the next section, the various food and non-food factors can offer the basis of a system of indicators for targeting assistance and may have limited forecasting capability. Ideally, however, the individual relationships between factors and nutritional outcomes need to be incorporated within a comprehensive modelling framework that can then be used to evaluate the comparative costs/effectiveness of resource allocation and intervention policies.

2.8 Monitoring and forecasting malnutrition

Before discussing the several approaches to forecasting malnutrition, it is appropriate to describe some of the information systems used by governments, international agencies and N.G.O.s to monitor malnutrition. In the majority, these systems are indicator based and fall into three main categories: supply side food statistics, nutritional surveillance and vulnerability assessment.

As noted in section 2.5, agricultural performance is the major component of food security for most developing countries. Following the 1974 World Food Conference, Early Warning Systems were set up to monitor the food supply in developing countries (Davies et al., 1991). Although food supply estimates were originally based on terrestrial data, these data have now been supplemented by crop yield estimates using satellite data about vegetation growth. The raw satellite data, in several frequency channels, are usually cleaned and processed to give a Normalised

Difference Vegetation Index (N.D.V.I.), which measures the difference in reflectance of biomass at ground level to the reflectance of bare ground. High levels of N.D.V.I. indicate the presence of biomass and differential N.D.V.I. between consecutive time steps provides an estimate of growth. For a summary of N.D.V.I. and its use in crop forecasting see Hutchinson (1991). Recently, satellite data used in Early Warning Systems have been made available on the World Wide Web (WWW) and include rainfall data as well as pre-processed N.D.V.I. data. Early Warning Systems are found within national governments, in regional centres and, at its headquarters in Rome, the Food and Agriculture Organisation of the United Nations (F.A.O.) maintains a Global Information and Early Warning System (G.I.E.W.S.).

In Zimbabwe, the Ministry of Lands, Agriculture and Water Development within the Government of Zimbabwe draws data from the regional Early Warning System for the Southern African Development Community (S.A.D.C.), based in Harare. It augments the S.A.D.C. system data with crop estimates from its own agricultural extension service, Agritex. These Agritex crop estimates are gathered on a four weekly basis, throughout the growing season, in each ward and aggregated at district, regional and national level for each of the main staples and cashcrops grown (see Appendix II for an example of the ward level data form in use in Manicaland). As Frankenberger (1992) notes (p. 80), quoting Shoham and Clay (1989): 'Indicators were developed on the basis of a food supply deficit model where the scale of the crisis could be measured at the macro (regional or national) level by shortfalls or deficits in supply of basic food stuffs in relation to aggregate population requirements. It was assumed that the crisis at the micro (individual or household) level would manifest itself in malnutrition or undernutrition. Thus, supply deficits were translated directly into a decline in nutritional status.'

Nutritional surveillance programmes complemented the macro supply analyses of the 1970's – represented by food 'balance sheets' – by monitoring the nutritional status of children as the representative indicator for the nutritional situation of the population as a whole. These programmes were implemented in health clinics and hospitals, where mothers were encouraged to attend health education prenatal classes and postnatal 'growth monitoring and immunisation' of the young child until aged five years. Zimbabwe operates just such a scheme and a copy of a 'growth monitoring

card' issued by the Ministry of Health is enclosed in Appendix III. Unfortunately, the chosen method of data collection – via health clinics – has identified the monitoring programme with the health sector, diminishing its influence upon wider rural development policy, which in Zimbabwe is the responsibility of the Ministry of Lands, Agriculture and Water Development. This is in line with a recent assessment by the Inter Agency Food and Nutrition Program (Frankenberger, *ibid.*), that suggested that this lack of influence may also have been caused by the presentation of outcome indicators rather than any analysis of causal factors (both food and non-food) related to economic decision making. In the early 1990's UNICEF implemented its plans (UNICEF, 1990) to encourage developing countries to broaden the scope of their nutritional surveillance programmes to meet these shortcomings.

Buchanan-Smith and Davies (1995) analyse recent case histories of five food crises in Africa. Their principal conclusion is that although the information components of the early warning systems are generally effective (albeit subject to over-centralisation – see below), poor decision making by the users of the information prejudices an effective response and slows the mobilisation of aid. They suggest that there is a 'missing link' between governments and donors that could be ameliorated by the joint ownership of early warning systems, so improving communication and thus the timeliness of response. They also highlight the centralised nature of such systems, observing that major wide-area famines are usually forecasted effectively and attended to by governments and donors. This wide-area effectiveness is often at the expense of forecasting smaller outbreaks of famine and/or the specificity of localised aid targeting.

Buchanan-Smith and Davies (*ibid.*) report (pp.165-201) the use of a localised early warning system in Turkana District, Kenya. This system was developed by the district government through the agency of a special unit the 'Turkana Drought Contingency Planning Unit.' Apart from its localised nature, two aspects distinguish the system from others in Africa. Firstly, it is concerned with providing early warning of impending food insecurity for a population consisting mainly of pastoralists (cf. the sedentary farming populations of much of southern Africa). The range of indicators selected reflects this. For example, livestock indicators of milk yields, bleeding - blood is consumed by the Turkana - and slaughter rates are chosen to measure

household stress. Secondly, in addition to the usual measures of rainfall, crop conditions etc. (supply-side indicators), the system collects market prices of staple grains and livestock (as demand-side indicators). In particular, it monitors the terms of trade between meat and cereals. Any deterioration in the ratio of price of livestock to maize flour signals the increase in de-stocking rates arising from a drought. The system uses the range of indicators to classify each quarter of the year as being in one of four warning stages: 'Normal', 'Alert', 'Alarm' and 'Emergency.' The system has a good reputation as a district-level implementation and it performed well in the 1990 and 1991 droughts in the area. However, in 1992, the most serious drought year of the three, the authors suggest (p.191) that the system '...seemed to have lost its edge in terms of being pro-active', with the result that clear messages for action were not given by the unit to the various departments of the district government and the NGO's working in the area. As a result, the authors report (p.197) '...the relief operation was launched a few months too late.' They suggest that this well-designed system, on its own was not sufficient, as in 1992 it lacked the assertiveness and political context that it had enjoyed in the earlier years. Interestingly, the authors reflect (p.198) that the Turkana system '...worked best for small-scale localised problems of food insecurity, which are overlooked by national and international early warning systems geared to full-blown, unmistakable emergencies. It worked least successfully for the district-wide crisis in 1992.'

Buchanan-Smith and Davies (*ibid.*) do not discuss the relevance of the 'malnutrition-infection complex' to famine early warning in general, although they comment upon the hygiene in refugee camps around food aid distribution centres in Sudan (p.107) and Kenya (p.172). In their earlier three volume work with other authors (Davies et al., 1991; Buchanan-Smith et al., 1991; Lambert et al., 1991), there is also little emphasis upon the interaction between malnutrition and infection. The need for intersectoral early warning systems, that combine health monitoring with the traditional food production forecasts, is not discussed. Surely it could be argued that this is also a 'missing link' that deserves attention?

2.9 Vulnerability and risk mapping

Vulnerability indicators represent a shift in attitudes brought about by Sen's theory of entitlements. Worsening food security came to be viewed as an erosion of a household's entitlements: its own production, other income, assets, gathering of wild foods and community support, as modulated by the behavioural responses and coping mechanisms adopted. From the late 1980's onwards, various governments, N.G.O.s and donors began to incorporate a range of food, socio-economic and environmental health factors into their monitoring systems, with a view to assessing the most vulnerable population groups. Frankenberger (1992) (p.82) cites several definitions of vulnerability: '...defencelessness, insecurity, exposure to risk, shocks and stress (Chambers, 1989) and difficulty in coping with them (Borton and Shoham, 1991)' and 'vulnerability is not equal to poverty – it is not lack or want (Downing, 1990)'. He argues that by splitting the concept into baseline vulnerability (the underlying factors), current vulnerability (shocks such as food shortages, exchange failure) and future vulnerability (coping ability) it provides a more useful basis for assessing household food security. His table summarising this 'household vulnerability assessment matrix' is shown in figure 2.9 below.

These ideas lead directly to the production of vulnerability/risk mapping projects in Bangladesh and Sudan (Borton and Shoham, *ibid.*) whereby geographical areas and population sectors are identified as being 'at risk' through their vulnerability to food insecurity. Use of vulnerability mapping has become widespread and is usually based on a combination of disaggregated existing data, specially commissioned field surveys, key indicators (e.g. market prices of staples) and rapid/participatory rural appraisals. Hutchinson (1991) reports that its use has been accelerated by the application of specialist software - Geographical Information Systems - to combine the different data within a consistent spatial reference frame. Webb et al (1995) review its application to Ethiopia, emphasising the importance of improving indicator selection and exploring a statistical approach 'Classification and Regression Tree analysis (CART)' to achieve this.

Risk of an Event	Ability to Cope			
Shocks/Trends	HH Characteristics	Access to Resources	Production/Income Opportunities	Support Structures
Baseline Vulnerability <i>Crop Production and Livestock Risks</i> drought episodes soil conditions pest infestations Market Risks market infrastructure price fluctuations (assets, food, cash crops, livestock) food shortages access to employment Political Risks conflict/war	composition (age dependency ratio) education health status out migration	access to land access to labor liquid assets productive assets credit common property resources (for wild foods and other products) food stores	crop/livestock production other income sources seasonal migration	community support mechanisms (claims) NGOs government policies access to social services
Current Vulnerability <i>Crop Production and Livestock Risks</i> current drought pest attack Market Risks market infrastructure price fluctuations (assets, food, cash crops, livestock) food shortages access to employment Political Risks conflict/war	composition (age dependency ratio) education health status outmigration	access to land access to labor liquid assets productive assets credit common property resources (wild foods and other products) food stores	crop/livestock production other income sources seasonal migration	community support mechanisms (claims) NGOs government policies access to social services
Future Vulnerability (trends) <i>Environmental Degradation</i> <i>Land Pressure</i> <i>Out Migration</i>	demographic changes	land tenure changes	employment trends	support structure changes

Figure 2.9 ‘Household Vulnerability Assessment Matrix’ (Frankenberger, 1992)

During the 1990’s several international agencies and N.G.O.s have amplified the techniques and there are now three recognised general methodologies to what has become known as ‘vulnerability assessment’ An F.A.O. report (Food and Agriculture Organisation of the United Nations, 1997a) describes these as follows:

- Risk maps (Save the Children Fund)** - Save the Children Fund’s approach to risk mapping seeks to develop an understanding of the food economy of middle, richer and poorer households within ‘food economy zones’ that are more or less homogeneous in their livelihood systems. In addition to using secondary data, much information is gathered by a systematic field approach that uses a sequence of semi-structured interviews with key informants at different levels down to village groups. This understanding is then collated and recorded in the database for a software program, ‘RiskMap’, which has been developed using a model of household food access and household and market responses in times of stress. The model can then be subjected to perturbation

(e.g. food production losses through drought) and an estimate of impact on household food income is projected and expressed differentially by wealth type of household. The net food shortfall is then mapped out in relation to the food economy zones. This is a bottom up approach in which an understanding of local economies is extended upwards to develop a picture of the region or country.

- **Indicators (U.S.A.I.D. Famine Early Warning System)** – An indicator approach is implemented by the United States Agency for International Development (U.S.A.I.D.). Its Famine Early Warning System (F.E.W.S.) seeks to infer conditions at the household level through an area level analysis. The primary types of information used include remotely sensed data (e.g. satellite observations of weather and vegetation response), official statistics reported by the government (e.g. agricultural statistics), and other information for which a sufficiently broad area coverage is available. Most of these data sets have a time series that is long enough (5-15 years) to establish reliable average conditions and to suggest general trends. For example, current conditions (e.g. estimated production) can be compared to average conditions for the period of record to give some indication of the magnitude of change. Data are interpreted against a conceptual model that describes household response to economic variation that is broadly similar to that of the Save the Children Fund. Because these data are continuous, they can be used to develop a general picture of degrees of chronic or baseline vulnerability, as well as vulnerability under current conditions. This is a ‘top down’ approach in which aggregate data are used to infer behaviour or conditions at a lower level.
- **Expert systems (l’Agence Europeenne pour le Developpement et la Sante (A.E.D.E.S.))** - The expert system approach used by A.E.D.E.S. is conceptually similar to the Save the Children Fund approach in its general structure, reliance on key informants and computerised implementation. It is similar to F.E.W.S. in that it reports by administrative unit. Several aspects of their approach have been emphasised. First, conceptually, while it focuses on household responses, it recognises explicitly that households are part of larger social structures (i.e., communities, clans and other social groupings) that help to insulate them from adverse conditions. Second, the reporting system itself is

embedded in the Early Warning System of host ministries and relies on ministry personnel at each level to provide the expert input. This use of ministry personnel does several things. First, it ensures some consistency to the information as it moves upward from the field, within the system. Second, the information generated is ultimately returned to the field so that it can be used locally. This adds positive reinforcement at all levels. Finally, the intent of the system is quite specific – to identify food aid needs. While it is acknowledged that the information generated may have other uses (e.g. development planning), these are not actively pursued.

Whilst there are differences in the methods of data handling, there seem to be similarities in the core components whereby households' organisation, behaviour and responses to endogenous and exogenous stress, form the basis of the conceptual models underlying the approaches. Furthermore, the indicator and expert system methods may be complementary. The use of indicators is ideal for the timely processing of large amounts of aggregate data, but poor at predicting the differing responses of heterogeneous households in any given location. Not only will responses vary with individual households' socio-economic characteristics, they will also vary with the characteristics of the community, the local economy and cultural differences. The report of Webb et al. (1995) stresses the need to combine household level assessment of vulnerability with *awraja*-level (an *awraja* being the equivalent of a ward in Ethiopia) analysis.

To collect and analyse data for formal models of response, for each household type within each location of application would require substantial resources and would not be timely, given the often urgent purpose of the vulnerability assessment: the targeting of emergency aid. To this end, the use of an expert system approach (not necessarily tied into ministries within governments, as per A.E.D.E.S.) should allow the rapid formulation of responses to stress.

Whilst each of the approaches above implicitly recognise temporal variability, by providing for vulnerability assessments to be carried out at different times during the agricultural season, none is explicitly dynamic in its method. The effect of this is that

the forecast of vulnerable households is restricted to a single point in the future (often within a short time after the data have been collected). Whereas, at other points in the future, other types of household may become vulnerable (and vice versa), but will have been omitted from the assessment. This suggests that vulnerability assessment by simulation may offer advantages, providing that the simulation model has a household focus within the context of the local socio-economic hierarchy.

2.10 Hierarchical structures

Hay (1986) writes that the claims of the poor to their share of what food is available are mediated by a hierarchy of relationships – households within communities, communities within countries and countries in the world at large – and the nature of these relationships constitutes the ‘political economy’ within which famines arise and must be analysed. It is suggested that any modelling framework must take account of such relationships by explicitly recognising these hierarchical structures.

The hierarchical structures associated with human communities usually embody some form of devolved powers and responsibilities associated with governance. Such structures are not limited to democratic systems, but are also evident in autocratic or tribal societies e.g. the Roman Empire, kraals and tribes in parts of Africa. This endogenous hierarchical structuring of populations should be differentiated from hierarchical structures arising exogenously from the perspective of the observer. (Anthropologists may argue that many of the socio-economic concepts of community hierarchies are similarly misleading in their rigidity.) Analytical tractability is enhanced by describing the processes of a system, whether human, biological or environmental, as operating at multiple levels. Thus, for example, models of global climate change split the meteorological processes into different layers, using different process models for each (Houghton, 1995). Layering of models in this way facilitates conceptual appreciation and may enhance data availability by distinguishing those components of the system for which data are more easily acquired.

Hierarchically structured data presents particular problems of statistical analysis. Early work by Aitkin et al. (1981) looked at the application of multiple regression techniques to the link between children’s reading ability and teaching styles. By

taking proper account of the grouping of children by classes and teachers, rather than treating the individual children as the only units of analysis, he refuted previous claims that formal teaching methods showed significant improvements in attainment. Recent work by several authors (Bryk and Raudenbush, 1992; Goldstein, 1995) has developed the theme of hierarchical or multi-level statistical analysis to provide guidance for its application in a variety of situations.

Improvements in statistical techniques for analysing hierarchical data have enabled researchers in many areas of social science, medicine and biology to take explicit account of hierarchies. Of note is the work of Wu and Loucks (1995), who describe a novel approach to modelling ecosystem change which they title: 'Hierarchical patch dynamics'. Patch dynamics is the modelling of changing levels of animal or plant populations (including colonisation and extinction) over time, on discrete spatial units ('patches'), each of which has a variable abundance of resources or other organisms. They suggest (page 439): 'The integration of patch dynamics with hierarchy theory has led to new perspectives in spatial and temporal dynamics with explicit linkage between scale and heterogeneity'. Of note is the assertion (page 459) that '....the spatial, temporal and organisational scales need to be explicitly linked, as models based on small scale processes are incorporated at larger scales with appropriate criteria and parameters for those scales'.

2.11 Simulation modelling

This section has been preceded by reviews of economic models (section 2.3) and by reviews of the methods used for monitoring and forecasting malnutrition (section 2.8), vulnerability and risk mapping (section 2.9) and hierarchical structures (section 2.10). Each of these sections has highlighted the need for a modelling approach that captures short-term variability in the local food system as a means of forecasting intra-seasonal change in nutritional status of individuals, within the context of their households' decisions. The reviews of existing approaches (sections 2.8 and 2.9) in particular stress the need of governments and agencies to be able to forecast and track such changes as the results of changes in exogenous variables (primarily rainfall and disease rates). This implies the need for a dynamic model of the food system, which reports interim results, as opposed to a single prediction of the future state of the

system. As such, the use of simulation modelling, as opposed to other dynamic modelling methods is an appropriate direction for the work herein.

However, as will be seen in the later chapters, much of the development of the simulation modelling framework is concerned with how best to represent the decisions made by farmers during the course of the agricultural year. As an alternative to simulation modelling, it has been suggested that Multiple Criteria Decision Making (M.C.D.M.) modelling may offer benefits. M.C.D.M. models are a particular class of mathematical programming (Winston, 1995) and the techniques for their implementation are closely related to those for Linear Programming. Mendoza and Prabhu (2000) summarise the technique (p.108) as follows: 'As the name implies M.C.D.M. is a decision-making tool that enables the rigorous selection of the most preferred choice in a context where several criteria apply simultaneously. In a rational decision-making environment, the most preferred choice is generally bounded by the management objectives and the constraints that limit the choices and the achievement of the objectives.' The main reported use of such models in agriculture and natural resources management has been to examine questions of resource allocation. For example, Mendoza and Prabhu (*ibid.*) discuss the application of M.C.D.M. to assessing the options for sustainable management of forests in Indonesia and examine the most suitable techniques for selecting the criteria and indicators used in the model formulation. Nkowni (1997) uses M.C.D.M. techniques to formulate multi-level models of farmer resource allocation and the consequential regional policy options in Zambia. He notes (p.53) '...micro and regional-levels should be integrated in a multisystems concept to understand and model decisions and linkages at and between all levels', but cautions against over-simplification at the farm level and in particular the unjustified assumption of homogeneity of farmer behaviour in a given location. Nhantumbo (1997) also uses M.C.D.M. to formulate multi-level models for the examination of policy options for agroforestry in Mozambique. She develops farm-level models for five different agroecological zones (which assume homogeneity of behaviour within these zones) within the study region and a regional model that examines the policy preferences of fuelwood, construction timber (poles), food, conservation and minimum budget. Her results are mixed, with some of the farm level models accurately predicting the observed resource allocation in the zone (e.g. the Dryland zone – see p.181), but with the regional model providing counter-intuitive

results, with the 'minimum budget' option apparently producing the best strategy and meeting most of the goals set (p.224). As Nkowni (ibid.) observes (p.52), M.C.D.M. models are prone to illogicality and misrepresentation of reality. Although such models may offer useful insights into the resource allocation problems of the types referred to herein, they are essentially concerned with a single set of decisions (e.g. allocation of land to crop types) and the subsequent outcomes for the year as a whole (or longer) in terms of income, food availability, environmental sustainability etc. As such they are far from ideal for the application required herein, where the purpose is to examine the changes occurring in small time steps (the frameworks developed in the chapters that follow use ten days), which are the result of mixing the decision-making in the household with stochastic processes such as disease, rainfall, etc.'

It appears that many researchers are considering the explicit recognition of hierarchies within their models and several ideas have been proposed for programming such structures. Advances in the applications of cellular automata (Wuensche and Lesser, 1992) have enabled researchers to model evolutionary development over extended time scales, by implementing simple deterministic rules for the interaction of adjacent cells. With object oriented programming methods (O.O.P.) (Booch, 1994) and more powerful computer processors, multi-layered simulations have become a feasible approach to the creation of hierarchical dynamic models of large systems. Gilbert and Conte (1995) report various models of social interaction, using cellular automata and O.O.P., to simulate and analyse contemporary societies and support the archaeological assessment of past community structures. Langton (1995) at the Santa Fe Institute, labels the subjects of such models as 'complex systems', which Casti (1997) defines as '... consisting of a large number of individual agents ... that can change their behaviour on the basis of information they receive about what the other agents in the system are doing. Moreover, the interaction of these agents then produces patterns of behaviour for the overall system that cannot be understood or even predicted on the basis of knowledge about the individuals alone. Rather, these emergent patterns are a joint property of the agents and their interactions - both with each other and their ambient environment.' Epstein and Axtell (1996) apply the software developed at the Santa Fe Institute, 'SWARM', to numerous highly idealised, economic and social scenarios. They report some success in producing community effects from the aggregate behaviour of individuals. Application of this type of complex systems

methodology has largely been limited to these sorts of restricted, artificial problems that explore the potential of the approach, rather than solve 'real world' problems. However, recent work reported by Railsback (1999) has successfully modelled predator-prey interaction during salmon spawning by simulating the shoal of returning salmon as individual fish and the river as a matrix of individual hydrological cells.

An alternative approach to simulating complex biological and ecological systems is the use of systems dynamic modelling (Hannon and Ruth, 1994). Rather than a set of individual objects, this approach specifies the system under study as a set of state variables and control variables, linked together as a dynamic system. The state variables represent stocks or accumulators of material or information. Flows or control variables update these state variables at each time period of a simulation. Complex interactions between components of the system can be constructed and feedback processes are permitted, although multiple levels of systems are not rigorously implemented. The various software packages (e.g. Stella II, Modelmaker) that employ systems dynamic modelling provide a graphical user interface to facilitate easy definition and editing of system parameters by users. These features, the explicit recognition of feedback within the modelling paradigm and the flexibility to control the time steps in a simulation are of attraction for the modelling of food systems.

Before completing this review of various simulation modelling techniques, the appropriateness of expert systems for simulating food systems will also be considered. Jackson (1999) provides a good introduction to expert systems and Durkin (1994) provides a review of their application. Such systems encode a human expert's knowledge and can be changed as the knowledge changes or is expanded. Jackson considers (p.76) the various methods available for encoding knowledge of which the most well known is the use of a rule base. He discusses the concepts of ordinary rules (whose role is to direct the reasoning required to solve the problem) and meta-rules (whose role is to reason about which of the ordinary rules should be scheduled for execution in order to address the problem correctly). The majority of expert systems applications are of a diagnostic type, whereby the expert system is presented with various data and the encoded knowledge base, translated into a set of rules, algorithms or heuristics is programmed to infer the conditions from which the data arose. The most well known early examples of this are probably MYCIN (Shortiffe, 1975), a

rule-based expert system which diagnoses infectious blood diseases from a combination of input data about symptoms and laboratory test results. The system was found to perform at a level comparable to that of the experts themselves, from whom the knowledge base had been encoded. In agriculture and rural development, Howells et al. (1998) report the use of an expert system, ECOZONE II, to assist with the preparation of environmental impact assessments.

Since the 1970's the area of expert systems research has burgeoned and is now a substantial part of the discipline referred to as 'Artificial Intelligence' (A.I.). Many more 'real world' applications of expert systems have been implemented successfully under the following headings:

- Control;
- Design;
- Diagnosis;
- Instruction;
- Interpretation;
- Monitoring;
- Planning;
- Prediction;
- Prescription;
- Selection;
- Simulation.

The last category has only one application cited by Durkin: STEAMER (Williams et al, 1983) which simulates and explains the operation of steam propulsion plants for U.S. Navy frigates. In relation to a survey of some 2,500 expert systems in use, in which 'Simulation' has the second lowest number of applications, Durkin remarks (p.23) '...tasks such as instruction, control and simulation, though they are excellent areas for expert system applications, are relatively new ventures of the technology,

giving rise to the few (*sic*) number of systems.’ This small number of expert system simulations being developed by the A.I. community would appear to be continuing as evidenced by presentations at the recent ‘4th World Congress on Expert Systems’ (Mexico City, March 1998), with the author’s own paper (Gundry et al., 1998) being alone in addressing this topic.

As noted in the previous section in relation to the expert system used by A.E.D.E.S. (a prediction application rather than simulation application), food systems will exhibit differences in behaviour in the different communities, cultures and environments. These differences will certainly be apparent in different countries and in different provinces of the same country. There may even be behavioural differences within relatively small areas of the same province. This has implications for the design of the modelling framework in that each implementation of the model will be location-specific and not necessarily transferable, without modification, to any other location. There are two approaches to this problem, which can be thought of as extremes of the same solution. Either a rigid, but comprehensive modelling framework is provided which allows the incorporation of sub-models having all alternative behaviours fully implemented and parameterised or a flexible modelling framework allows for easy update of behaviours within sub-models as new scenarios are simulated. Clearly, the ideal will be a balance of these two approaches, but the use of expert systems methodology for the modelling framework will allow users to encode and modify some or all of the sub-models relatively easily.

2.12 Remarks

From the literature, it seems that the first part of sub-objective 1: *‘To establish that methodologies for nutritional, physiological and micro-economic analyses of subsistence farming communities are well documented...’* can be met, although there would seem to be differences in scale between different researchers’ findings and models. Hence there will be a need to draw data from the field survey and secondary data collected to ensure that sub-models for each discipline *‘...can be developed and are suitable for inter-related use’*. This inter-relating of sub-models (either models from differing disciplines or models operating at differing scales) has only been achieved in a limited way by the three existing modelling approaches used for

‘vulnerability assessment’. These are mainly concerned with food shortages, with substantial amounts of data provided by supply side statistics from governments and international agencies. Although W.H.O. and UNICEF emphasise the importance of the interaction of malnutrition with infection and care, the explicit incorporation of health sub-models and data in food system models is absent. Similarly, multi-level modelling is not a feature of the three approaches. Thus, following the literature review, the approach taken in this work was to design a modelling framework that uses the ‘malnutrition-infection complex’ as its core process and analyses the food system at several levels, with linking of the appropriate sub-models at each level. Such a multi-level modelling framework would then automatically take account of spatial variability. Temporal variability, primarily related to the seasonality of agriculture (and infection incidence), was also an essential feature, implying a dynamic, as opposed to static, modelling framework. The resultant ‘shortlist’ of modelling approaches was therefore seen to be:

- **Systems dynamic modelling** – *Advantages*: inherently dynamic, explicit recognition of the overall system, good availability of software, easy modification of models by users. *Disadvantages*: multi-level system linking not straightforward, multiple ‘objects’ require multiple full models rather than multiple data alone.
- **Object oriented programming** – *Advantages*: powerful and flexible, explicit recognition within object paradigm of multiple levels and interactions between objects. *Disadvantages*: available software limited to ‘SWARM’ which until recently did not operate on personal computers (a requirement of the European Union research contract), computer programming knowledge therefore necessary for design and development of the framework and modification of any implemented model.
- **Expert systems** – *Advantages*: ideal for capturing large quantity of behavioural rules about individuals, households etc., modification of implemented models easily accomplished by changes to knowledge base, wide availability of software. *Disadvantages*: simulations using expert systems are uncommon and existing software reflects this, multi-level models not easily implemented.

In 1996, as no pre-written personal computer based software was available that used object oriented programming, the decision was taken to use a dynamic systems modelling approach and the package 'Stella II' was selected to design the prototype framework.

As discussed in chapter 5, this approach proved to be flawed by the disadvantages shown above for systems dynamic modelling. In particular, the inability to allow multiple instances of modelled objects resulted in the designed framework being unable to adequately represent heterogeneity amongst objects within any given layer. Despite this, the choice was not worthless as significant insights into the more general problems of the design were gained.

3 Household survey

3.1 Purpose

Primary and secondary data were collected to provide the detail necessary to support the development of the nutritional, physiological and micro-economic sub-models. A household survey was undertaken and various secondary data collected from government and other institutions (see chapter 4) to characterise household and community resources. The purpose of this chapter is to provide background to the study district of Buhera, to outline the scope of the household survey (including the related anthropometry) and to confirm the need for the modelling framework to allow users to take account of temporal and spatial variability in implementing models. In preparation for the building of individual sub-models, research assistants and collaborating scientists analysed various elements of the household survey data relating to their own discipline, implicitly taking account of these variabilities. These analyses are not reported in this thesis. However, to obtain a consistent view of the extent of temporal and spatial variability, the author carried out a set of simple Chi-squared tests, looking at all the data characterising household resources, whether demographic, agricultural, socio-economic or nutritional. The results of these tests are described herein.

3.2 Buhera district

Buhera District (see Figure 1.1) in Manicaland Province was selected as the research area for the project. The criteria for selection included: relative remoteness from the two main cities, Harare and Bulawayo, to provide a rural as opposed to a peri-urban socio-economy; wholly subsistence farming rather than small or large scale commercial agriculture; and a district that was not the subject of any other field surveys of a similar type. Buhera is located about 200 km. to the south east of Harare. Manicaland is the easternmost province of Zimbabwe, with the Chimanimani and Nyanga mountain ranges providing a natural border with Mozambique. It is one of nine districts, approximately 5,400 sq. km. in extent with a population of 203,739 at the 1992 census (Government of Zimbabwe, 1994) and is divided into 30 wards. There are no major towns in the district (or close by) and thus the socio-economy is

essentially rural. The district is bounded by two rivers: the Save to the east and the Nyazwadzi to the west. There are only two tarmac roads in the district. The first is a minor road in the northwest that accesses the Grain Marketing Board depot in the town of Buhera. The second, is a trunk road connecting Mutare with Masvingo, which just crosses the most southerly wards (see Figure 6.1). These two state roads run east/west and north/south, with secondary roads of variable quality feeding to these. The secondary roads are built and maintained by the District Development Fund (the local government body responsible for infrastructural projects). The interior of the district is served by a poorly maintained system of unmade tertiary roads and tracks. Buses operate along the tarmac and secondary roads, but services are restricted in the rainy season due to the impassability of some routes. These buses are operated by the National Bus Company of Zimbabwe and connect the district with the three closest cities, Harare, Mutare and Masvingo. There is no rail service.

The district is comprised of semi-arid Communal Lands and is classified in the three least productive of the five agro-ecological zones of Zimbabwe (see Figure 3.1). The southern part of Buhera falls under zone V where rainfall levels average 500 mm are low and the lands unproductive. The central section is zone IV, with average rainfall of 650 mm. The quality of land improves in the northern third of the district, falling under zone III with an average 800 mm of rainfall. Historically, maize has been the predominant crop in the north of the district, and in most years, is food self-sufficient in aggregate. Towards the south, farmers plant an increasing proportion of more drought resistant crops, such as sorghum and millet. Most households keep some animals, cattle, goats or chickens.

The District Administrator and Council, together with the local Agritex (agricultural extension service) and District Development Fund are located in the business centre (small town) of Buhera in the north west of the district. The only hospital and Ministry of Health administration is in Murambinda, some 40 km. to the east. There are some 33 rural health clinics and 20 outreach centres scattered throughout the district.

3.3 Household characteristics and diet

Households, averaging five persons in the study area of Buhera, will generally inhabit two or more single room residential units (thus separating children's and adults' sleeping quarters) within a cleared yard area. Houses are usually located in groups, with tribal ties between the families. These groups are known as '*kraals*' and represented by a *kraal* headman who sits on the Village Development Committee ('vidco'), the administrative unit below ward level. The houses will be either of traditional construction (circular with a superstructure of wooden poles, mud ('*dagga*') walls and a thatched roof) or more modern, with brick and corrugated steel roof. Type of housing is linked to nutritional status both through health, by quality of shelter and ventilation and as a badge of wealth and hence an implied higher level of food access. Other buildings may include animal pens or huts, grain storage facilities and 'Blair toilets' (non-flushing lavatories with improved sanitation). Water supplies will generally be from a shared borehole or protected well within the *kraal* area or an unprotected water source such as a dam or stream. Access to water sources can vary seasonally. Owned or shared electricity supplies are rare in these rural areas. More than ninety percent of households in Buhera use charcoal as the main fuel source (Government of Zimbabwe, 1994). Apart from limited household furniture and cooking utensils, other assets will include agricultural small tools and, for the richer households, a plough, a 'scotch' cart (two wheeled and open topped) and perhaps a bicycle.

Each household will have limited rights of ownership of farmland in the neighbourhood for arable production (average 2 hectares in Buhera), usually inherited through the traditional patrilineal system. There may also be a vegetable garden close by the house. The land rights under this system are controlled by the tribal chiefs, who also allocate or re-allocate land when new households are created. The chiefs also resolve disputes. Agricultural activity usually includes both arable production and animal husbandry. In poorer households, arable agriculture is limited to the principal staples: maize, sorghum, millet and groundnuts, whilst in others it includes some cash crops: burley tobacco and cotton. Most households rear some animals, usually goats and chickens, for sale or for consumption at festivals and funerals. During the daytime, these animals roam freely close by household, feeding on bushes

(goats) and insects / grubs (chickens). Any minor supplementary feeding will be from waste arising during human food preparation. Richer households keep oxen for draught power and cows for milk. Cattle are grazed on communal land and grazing is not allocated to individual households. Cattle are given maize husks as a supplementary feed. In common with subsistence households throughout sub-Saharan Africa, cattle are highly prized, particularly for their service functions to arable farming activities and for transport. Cattle are rarely slaughtered for consumption. In most households, meat (usually from own-reared goats, chickens or small game animals) is eaten only about once per week, with slightly more frequent consumption of dried fish, which is purchased locally, although harvested in Lake Kariba about 1,200 km. away! The predominant food is '*sadza*' (a porridge made from maize meal) accompanied by relishes of vegetables or groundnuts.

In addition to working on owned land, poorer households will supplement income with the sale of handicrafts and the hiring out of labour on a casual basis to the richer farmers. There are no large-scale mining, manufacturing or raw material industries in the study district and the service sector is restricted to local government, education, agriculture extension offices and health clinics. Any individual employed in the service sector, no matter how lowly a position, would be in receipt of a stable income and thus able to buffer the effects of any agricultural income shortfalls. In Zimbabwe, as in other developing countries, this need to supplement agricultural income has led to substantial migration from rural areas to the cities. Households in Buhera often have one male (husband or a son) working away in Harare or another city, for all or part of the year. These migrant workers send money or goods home – 'remittances' – on a frequent but irregular basis. In Buhera and throughout the rural areas of Zimbabwe, remittances form a substantial proportion of total household income and thus are an important determinant of a household's food access. Indeed, for the agricultural year of the study, remittances formed more than half the average aggregate income for all households in the sample frame.

The impact of these migrant workers on the social fabric of rural communities is difficult to gauge. The 1992 census (Government of Zimbabwe, 1994) found that 44% of households in Manicaland (the study province) were headed by females on the night of the census, albeit that in many cases the male heads will have been working

away in the cities. The survey found that 18% of households had only a female head and no absent male head. These will be widows or unmarried women, living alone or with children i.e. genuine 'female-headed' households. Polygamy is also practised in Zimbabwe, with each wife and her children having a separate dwelling and thus classified as a separate household for census purposes. Although men return to the home villages at times of planting and harvest, the women and children carry out the majority of the agricultural labour. This has significant implications for household energy requirements and decision making about resource allocation.

Harvest time in Zimbabwe is in March / April and households generally sell some surplus grain during the months post harvest, retaining the remainder for household consumption for the rest of the year. In January / February, when the new season is well underway, household heads will gauge whether household requirements in the coming months can be met from 'green maize' (ripening cobs) and other growing crops. If so, further sales of surplus maize, stored from the previous season, will be made. Highly local trading remains the most usual route with households in surplus selling to those in deficit, either for cash or in return for labour. However, once local demand has been satisfied, surplus grain will be sold to traders or transported to the nearest parastatal Grain Marketing Board depot for sale. Until 1994, grain trading in Zimbabwe was restricted to the Grain Marketing Board, other than for sales within the same district. Since 1994, private traders have been permitted and the Grain Marketing Board has become the buyer/seller of last resort, effectively setting bounds on the market prices with pan-territorial and pan-seasonal prices for maize and some other staples. An analysis of the economics of this mix of household rationing behaviour and grain trading is given in Vaze et al. (1996a). Note however that some of the poorest households adopt a different strategy immediately post harvest and sell all their grain, due to their needs for cash to meet loan obligations, school fees and health clinic charges. Later in the year, they will hope to be able to buy food in the market as required from earnings of casual labour and other sundry income. This strategy of reliance on current period purchasing to meet food requirements implies increased vulnerability for the poorest households. They are exposed to short term contraction in the local economy, with consequential shortage of work and thus income from which to buy food. They are also exposed to rising food prices, where these are unmatched by rising wages for casual employment.

The importance of customary behaviour by households should be emphasised. Whilst tribal ties are loosening somewhat in Zimbabwe, family relationships and obligations remain strong, as does the sense of belonging to the 'home' village or *kraal*. Even where individuals move away to cities for the majority of their adult life, it is likely that they will retain links with their home village, by remittances of cash or assets to the resident family members and by investment in the farm, usually by purchases of oxen. Upon retirement they will return to the village, for support from the younger generation and a share of the agricultural income. This mutual support by members of the extended family also operates in times of hardship, with grain or cash flowing between rural and urban areas, depending on personal circumstances. Such transfers are important in the context of a household's overall nutritional security. During the survey year, 16% of households reported receiving support from these sources.

Rural Zimbabwe is relatively well served with education and health facilities, although following the Economic Structural Adjustment Programme (E.S.A.P.), both schools and clinics were required to charge attendance fees. In addition to the hospitals and clinics, outreach centres are operated in remoter areas by visiting health workers and each vidco has a nominated Village Community Worker, whose duties include assisting with home births, reporting deaths and treating non-chronic illnesses. Clinic and hospital attendance is restricted to chronic cases or accidental injuries. Zimbabwe has initiated a prenatal and postnatal counselling, immunisation and monitoring programme, records of which are collated to produce the national malnutrition statistics. Note that independent field studies suggest that such statistics understate the incidence of malnutrition as clinic attendees tend to be the mothers who can afford to pay the fees and/or have a better understanding of the need for child care, see Wright (1998). Other prevalent diseases include, for children: diarrhoea, malaria, bilharzia, respiratory disease, goitre, measles and for adults: malaria, tuberculosis, AIDS/HIV. Disease statistics are compiled from clinic records and are also likely to show bias because of variation in clinic usage amongst income groups (the extent of HIV infection, especially amongst children, is particularly problematical in this regard), see Wright (1998).

Membership of the Apostolic faith is widespread in Zimbabwe, particularly in rural areas. In the survey 37% of households had one or more adults who were 'Apostolic'. The religion prohibits the use of medicines and invasive clinical treatment. Adults in Apostolic households shun the use of the medical services, both for themselves and their children. During the survey, all the children in one Apostolic family contracted measles, their parents refused treatment and the children died. Membership of the faith will largely obviate the benefits of the availability of good clinic services and it is an important household characteristic to be considered in the analysis of factors that influence health.

3.4 Household sample frame

The Food and Agriculture Organisation's Senior Agricultural Statistician in the F.A.O./S.A.D.C. Early Warning System office in Harare, Dr B.P. Goel, assisted the research project with the detailed design of the sample frame for the household survey. He suggested the use of a stratified sample, taking the stratifying variables as the expected most significant factors determining the nutritional security of households, as detailed below. Stratification ensures that a sample contains households that reflect the presence or absence of certain characteristics believed to be the most important factors in the relationship being investigated. Herein, three stratifiers were used: agro-ecological zone (a proxy for agricultural performance); ward-level quality of access (a derived measure reflecting access to markets, health facilities and agriculture extension services) and kraal-level access to water (both quality and distance of source). These are all recognised as influencing household nutritional security. An additional stratifier within kraal e.g. household size, sex of household head may have been useful, but was not pursued.

N.B. From a practical standpoint, it is considerably easier to persuade villagers to take part in a survey when the selection of households is random, without stratification. There is often suspicion as to the motives of survey teams (links to government etc.) and separating strata before selection would appear to suggest bias on the part of the researchers, the reasons for which would be difficult to explain.

The sampling plan was designed to cover the whole district, regardless of accessibility for survey teams. All wards in Zimbabwe are split into about six Village Development Committees ('vidcos'). Figure 3.1 shows the ward and vidco boundaries for Buhera, overlaid with the agro-ecological zones. The selected vidcos are shaded.

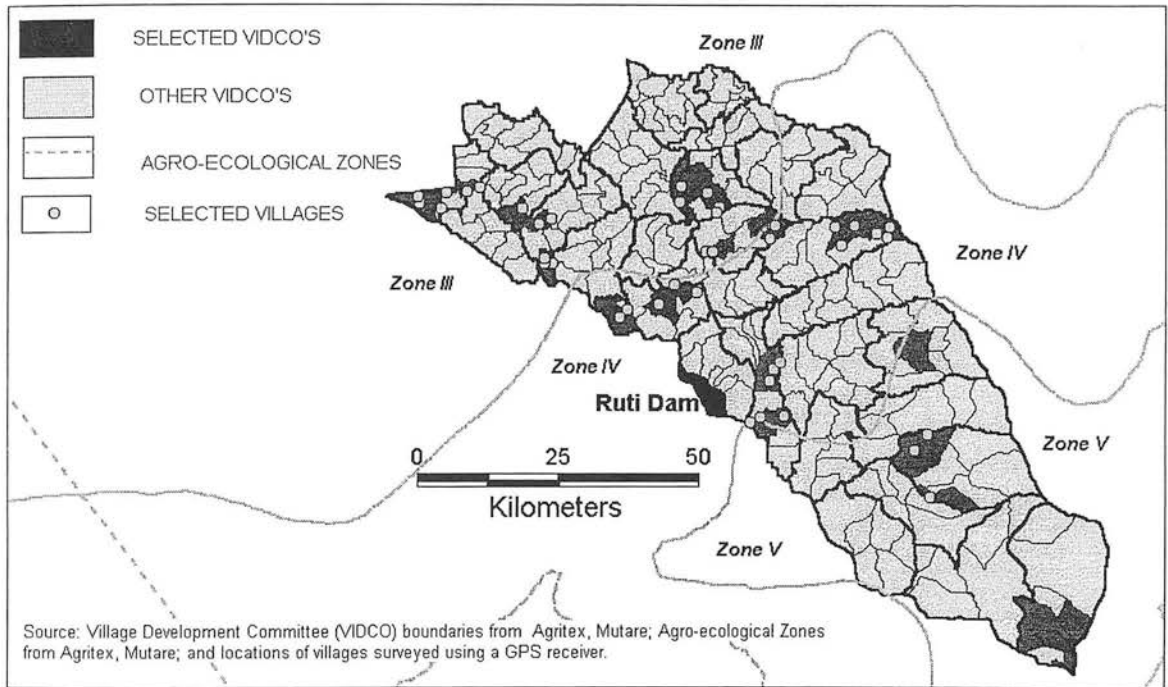


Figure 3.1 Study district of Buhera, with sample locations

A representative sample of ten wards was selected, stratified by agro-ecological zone. For the sample, within each selected ward, vidcos were stratified by quality of access to local infrastructure. This 'quality of access' was derived using a geographical information system (G.I.S.) to evaluate transport availability and distance for each vidco to each element of infrastructure within the district – markets, business centres, healthcare facilities and agricultural support – and wards classified either side of the median as 'good' or 'bad'. For more details of this G.I.S. technique, see Wright (1998). One 'good' and one 'bad' vidco were randomly selected from each ward. 'Village' has no exact equivalent in rural Zimbabwe, with the communal unit below vidco being the traditional '*kraal*' or grouping of households. These households are within the same tribe, are usually related and governed by a *kraal* headman who has administrative powers and sits on the Village Development Committee. For the sample, three *kraals* within each vidco were selected, using water access as the

access as the stratifier. Water access is cited by many nutritionists e.g. Lindskog et al. (1988) as being an important determinant of 'infection' within the 'malnutrition-infection' complex. Water access comprises two aspects: quality (protected sources, usually wells, boreholes and unprotected sources, streams lakes and dams) and distance to collect water, which impacts upon quantities used and labour/energy requirements for collection. Finally, six households were selected at random in each kraal. Thus the total sample comprised 360 households. The sampling plan is summarised below:

Layer	Total	Sample	Stratifier
District	1	1	None
Agro-ecological zone	3	3	None
Ward	30	10	Agro-ecological zone
Vidco	180	20	Access to infrastructure
Kraal	1,800	60	Access to water
Household	40,000	360	None – random

Table 3.1 Sampling plan for the household survey of Buhera District 1994/95.

The household survey commenced in November 1994 and was completed in December 1995. The survey covered demography, agriculture, income, assets, food consumption and anthropometry, with several topics being repeated to take account temporal variability across the 1994/95 agricultural year, to give eleven rounds in total. The project office was based in Harare and a four-wheel drive vehicle used to visit the field locations and co-ordinate the survey with the resident enumerators. Ten enumerators were hired for the complete season, one from each sample ward. Enumerators used standardised questionnaires that had been prepared in English and translated to the local language, Shona, by one of the collaborating institutions, the University of Zimbabwe. Training was given in the use of the questionnaires before each survey round to minimise any likelihood of misinterpretation. The timetable of the survey and a brief description of each round is shown in table 3.2 below.

Survey round	Month	Questionnaire	Why survey month selected?
1	Oct 94	Demographic #1 Household Assets & Income #1	
2	Nov 94	Food consumption #1 Food frequency #1 Health status #1 Anthropometry trial	Food/health/energy stress
3	Jan 95	H'hold & agric assets Year1	
4	Feb 95	Food flows #1 Off-farm & l'stock income #1	Maximum food purchases Need school fees cash
5	Mar 95	Food consumption #2 Health status #2 Anthropometry #1	Food/health/energy change
6	May 95	Crop production #1	End of season
7	Jun 95	Food flows #2 Off-farm & l'stock income #2	Min turnover of food stocks Post harvest income sources
8	Jul 95	Food consumption #3 Health status #3 Anthropometry #2	
9	Sep 95	Demographic #2 H'hold & agric assets Year2	
10	Oct 95	Food flows #3 Off-farm & l'stock income #3	Grain loan / food aid
11	Nov 95	Food consumption #4 Health status #4 Anthropometry #3	

Table 3.2 Showing primary survey timetable and questionnaire rounds.

As shown in Table 3.2, there were three rounds of anthropometry (March, July and November) in which members of the households were measured for height and weight. In addition, the mid-upper arm circumferences of children were measured –

recognised as a good proxy for full body anthropometry. These data were collected by provincial nursing staff from the Ministry of Health, supervised by a qualified research from the Italian collaborator, the Istituto Nazionale della Nutrizione in Rome.

One particular aspect that needs special mention is the incidence of polygamy in the study district. In common with many countries in Africa, polygamy is practised, with men having two or more wives, each located in a separate household. This separation can be clear in some families and much less obvious in others. It is apparent that relationships between wives of the same man are often quite friendly, albeit that the first wife generally has informal authority and influence over some aspects of household management and childcare, outwith her own household and children. For the purposes of the survey, polygamous households were treated as separate but related households, with one sub-household for each family where members ate from the same cooking pot. For the purposes of the development of the simulation model however, it has become clear that separation into sub-households presents particular difficulties when assessing the income distribution from the male head of these sub-households (who is one and the same person and presumably, the father of all children therein). To alleviate this problem, the survey data for polygamous sub-households have been recombined into single 'super households', but with indicators of polygamy. For the data relating to the individual household members of these polygamous sub-households, an additional indicator of blood relationship to household head and identity of wife have been added before recombination into the 'super households'. This recombination has reduced the number of households in the sample from 360 to 348.

3.5 Data collected

The data were for each round were recorded on questionnaires, each of which was cross-referenced with a unique household identifier. Data from both the household surveys and the anthropometry were input into the project database at the office in Harare. The questionnaires were initially collated by survey round and the data checked manually before keying. The data were then overkeyed to validate the initial input. At the conclusion of the survey, all of the questionnaires were photocopied to

provide two complete sets. Each set comprised 360 ‘books’, with each book containing the data for all rounds for one household. The original set has been retained by the collaborating institution, the University of Zimbabwe and the photocopied set is held at the University of Edinburgh.

Despite the efforts made to control the recording and keying of the collected data, subsequent review has shown errors and inconsistencies between data from different rounds. These have necessitated extensive resources to clean the data further. A subset of the original database has been produced, including only those elements necessary for the development of the nutritional, physiological and micro-economic sub-models. A copy of this file has been provided to each researcher involved in the project, to ensure consistency of analyses.

With hindsight, the data collected were excessive for the project purpose, with each team member having requested comprehensive information for their own particular research area. Possibly this is the nature of multi-disciplinary research, but in retrospect significant resources would have been saved if the planning had included stricter evaluation criteria for each data element.

The issued file in the form of a database comprises two tables:

- **Households**, containing 348 records.
- **Individuals**, containing 2,264 records, cross-referenced by household identifier.

The fields of each table are shown in Tables 3.3 and 3.4 below.

N.B. In the ‘Rounds’ column of each table: ‘Static’ indicates that the data were considered to be unchanging over the period of the survey; R1, R2, R3 and R4 indicate survey rounds occurring at different points in the agricultural season November through October; Y1, Y2 are the agricultural seasons 1994/95 and 1995/96. All currency fields are in Zimbabwean dollars.

Field Name	Format	Rounds	Description
Household ID	Number	Static	Unique reference number
Ward ID	Number	Static	Unique reference number
Zone ID	Number	Static	Unique reference number
Market km.	Number	Static	Distance to nearest market
Under 5's	Number	R1	No. children under 5
Under 10's	Number	R1	No. children over 5 and under 10
Males 10 to 14.9	Number	R1	No. children over 10 and under 15
Females 10 to 14.9	Number	R1	No. children over 10 and under 15
Males 15 to 17.9	Number	R1	No. males over 15 and under 18
Females 15 to 17.9	Number	R1	No. females over 15 and under 18
Males 18 to 21.9	Number	R1	No. males over 18 and under 22
Females 18 to 21.9	Number	R1	No. females over 18 and under 22
Males 22 to 49.9	Number	R1	No. males over 22 and under 50
Females 22 to 49.9	Number	R1	No. females over 22 and under 50
Males over 50	Number	R1	No. males over 50
Females over 50	Number	R1	No. females over 50
Sanitation	Text	Static	None, latrine, Blair facility, W.C.
Polygamy	Yes/No	Static	Was the household polygamous?
Non-agric income?	Yes/No	Y1	Was non-agricultural income received?
Apostolic faith?	Yes/No	Static	Was the household of Apostolic faith?
Kinship Crop Gifts	Yes/No	R1-R3	Did extended family get/give crops?
Hired labour?	Yes/No	Y1	Was labour hired in during season?
Plough?	Yes/No	Y1,Y2	Was a plough owned at start of season?
Store?	Yes/No	Static	Did the household have a grain store?
Scotch Cart?	Yes/No	Y1,Y2	Was a cart owned at start of season?
Cattle category	Number	R1-R3	0=None; 1=1-4; 2=5-9; 3=10+
Goats category	Number	R1-R3	0=None; 1=1-4; 2=5-9; 3=10-29; 4=30+
Chickens category	Number	R1-R3	0=None; 1=1-4; 2=5-9; 3=10-29; 4=30+
Wild food?	Yes/No	R1-R3	Were wild foods eaten in the month?
Food groups	Number	R1-R4	How many food groups were eaten?
Maize kg	Number	R1-R4	Stock of maize

Small grains kg	Number	R1-R4	Stock of sorghum, millet, rapoko
Nuts kg	Number	R1-R3	Stock of ground nuts
Total kcals	Number	R1-R4	Aggregate equivalent kilocalories food
Livestock net income	Currency	R1-R3	Net sales/purch of livestock & products
Remittances	Currency	R1-R3	Remittance income
Garden?	Yes/No	Static	Did the household have a garden?
Fertilizer (garden)?	Yes/No	Y1	Was fertiliser used on the garden?
Fertilizer (fields)?	Yes/No	Y1,Y2	Was fertiliser used on the fields?
Irrigation?	Yes/No	Static	Was any land irrigated?
Maize percent	Number	R1-R3	% land for maize
Small grains percent	Number	R1-R3	% land for sorghum, millet, rapoko
Nuts percent	Number	R1-R3	% land for ground nuts
Cash crops percent	Number	R1-R3	% land for cash crops
Crop area	Number	R1-R3	Crop area in hectares
Housing type	Text	Static	Traditional (T), modern (M), mixed (X)
Water source	Text	R1-R3	Protected (P) or unprotected (U)
Sex of hhold head	Text	R1	Sex of household head
Age of hhold head	Number	R1	Age in years of household head
Educ of hhold head	Number	R1	Education level in years of h'hold head
Educ of wife	Number	R1	Education level in years of (first) wife
Food aid?	Yes/No	R1-R3	Was food aid received in the month?
Non-agric income	Currency	R1-R3	Non-agricultural income
Crop sales	Currency	R1-R3	Receipts from crop sales
Crop purchases	Currency	R1-R3	Payments for crop purchases
Food buy	Currency	R1-R3	Payments for food purchases
Hhold goods/services	Currency	R1-R3	Payments for goods/services
Total expenditure	Currency	R1-R3	Total payments

Table 3.3 Household variables in the primary survey database (sample size = 348).

Field Name	Format	Rounds	Description
Household ID	Number	Static	Unique reference number
Individual ID	Number	Static	Reference number within household
Sex	Text	Static	Male or Female
First name	Number	Static	First name of individual
Surname	Number	Static	Family name of individual
Pregnant?	Number	R1-R3	Pregnant at time of survey round?
Day of birth	Number	Static	Day of month of birth
Month of birth	Number	Static	Month of year of birth
Year of birth	Number	Static	Year of birth
Age	Number	R1-R3	Age at date of survey round
Height	Number	R1-R3	Height in cm
Weight	Number	R1-R3	Weight in kg
Average height	Number	R1-R3	Average height across 3 rounds, in cm
BMI	Number	R1-R3	Body Mass Index
WAZ	Number	R1-R3	Weight for Age Z-score
HAZ	Number	R1-R3	Height for Age Z-score
WHZ	Number	R1-R3	Weight for Height Z-score
Mortality status	Yes/No	R1-R3	Alive; Dead; Unborn at time of survey round
Relationship	Number	Static	Code for relationship to household head
Residency status	Yes/No	R1-R3	Resident at time of survey round?
Non-residency	Yes/No	R1-R3	Code for reason for non-residency

Table 3.4 Individual variables in the primary survey database (sample size = 2,264).

3.6 Summary findings

As noted at the beginning of this chapter, this thesis will not report the detailed statistical analyses of the household survey data that have been completed by other researchers working on the collaborative research project. However, the summary findings, as given in a contemporary report to the European Commission (Gundry and Ferro-Luzzi, 1996) are shown at the end of this section.

After amalgamating polygamous households, the survey comprised 348 households and the 2,264 individuals 'belonging' to these households. 'Belonging' needs explanation: the survey included all household members who were resident at any survey round, including long-stay visitors e.g. extended family members and non-resident household members who were ordinarily resident for a proportion of the year. The latter category principally comprised adult male migrants working in cities, remitting funds to the household and returning periodically for family visits and to assist with agricultural work.

The survey period (November 1994 to December 1995) included the 1994/95 agricultural season. Household yield data and local grain prices were obtained for the survey year only. In aggregate for the Buhera District, the season was considered to be a drought year, as shown in Table 3.5 below.

Season	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
92/93	0	0	0	5	118	305	195	71	6	54	0	5	760
93/94	28	1	0	0	201	75	155	60	2	31	0	0	553
94/95	0	0	5	77	12	162	62	26	81	2	7	0	434
95/96	1	0	0	21	144	170	348	93	26	1	60	12	876
LT avg	0	0	0	0	94	196	153	156	68	33	0	0	700

Table 3.5 Monthly rainfall in mm for the Buhera Meteorological Station, 1992/93 to 1995/96, with the long term average. Source: Government of Zimbabwe (1995a).

The Buhera Meteorological Station is located in the northern part of the district. Although the aggregate seasonal rainfall was much below the long-term average, the monthly rainfall showed marked variability between agro-ecological zones.

From the table above, a cumulative rainfall graph shows the shortfall in precipitation by January. This graph is shown in Figure 3.2 below.

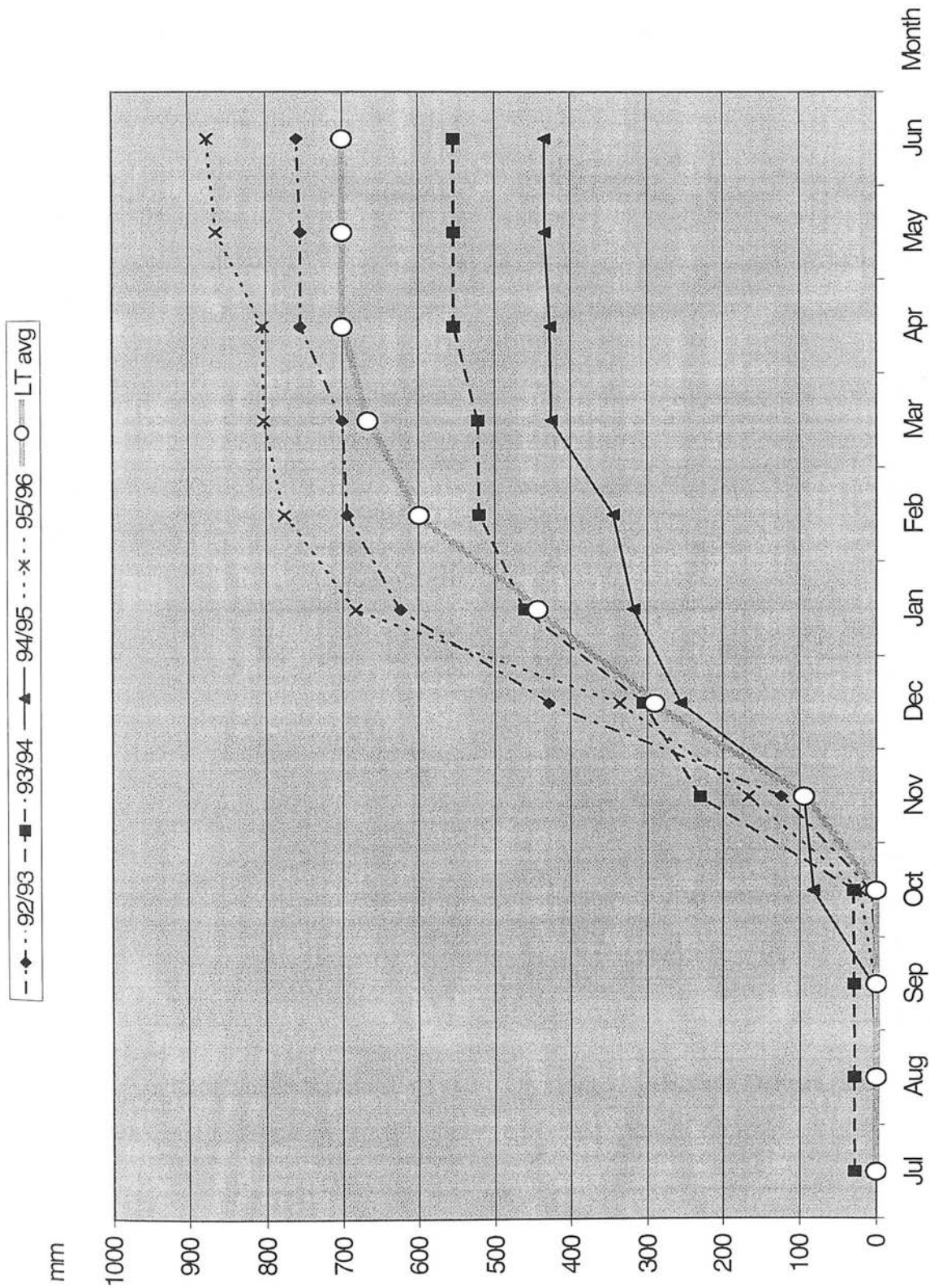


Figure 3.2 Cumulative annual rainfall 1992/93 to 1995/96 Buhera Meteorological Station Lat 19 19S Lon 31 26E Alt 1190M

In some parts of the district, rains greatly exceeded the long-term monthly average for December, causing localised flooding in some rivers. This caused crop losses for those farmers who had planted close to river in expectation of average rainfall.

However, in January and February, critical periods of growth for maize, rainfall was nil to very light across most of the district. The maize crop in most areas failed to 'tassel' i.e. the maize cob not maturing and producing the characteristic dark brown tassel of fibres at the top. Small grains – sorghum, rampoko and '*mhunga*' (millet) – were even more badly affected. All crops were badly affected, but yields, though sharply reduced, were in line with agro-ecological zoning being higher in the northern part of the district (agro-ecological zone III) than in the central and southern parts (agro-ecological zones IV and V). Harvests in Buhera were amongst the worst in Zimbabwe in 1994/95.

For the surveyed households the mean maize yield was 175 kg/Ha (22% of the 10 year average) and small grains 70 kg/Ha (13% of the 10 year average). The 10 year yields for all crops are shown in Table 3.6 below and the four food crop yields plotted on Figure 3.3 overleaf.

Crop	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	Avg
Maize	180	630	1800	450	450	1620	720	1440	630	90	801
Sorghum	182	540	910	0	364	1365	450	810	364	45	503
Rampoko	182	364	910	270	455	910	630	990	364	1	508
Mhunga	180	540	1365	0	637	1365	630	810	360	1	589
Groundnut	3	8	10	3	15	20	12	640	9	80	80
Soyabean	0	5	0	0	2	10	4	540	3	0	56
Sunflower	0	6	5	5	8	15	9	825	7	1	88
Cotton	0	360	700	0	600	800	540	660	468	180	431

Table 3.6 Crop yields (kg/Ha) for 1982/83 to 1991/92 in Buhera District (Sources: Agritex Communal Lands crop database and Government of Zimbabwe (1995b))

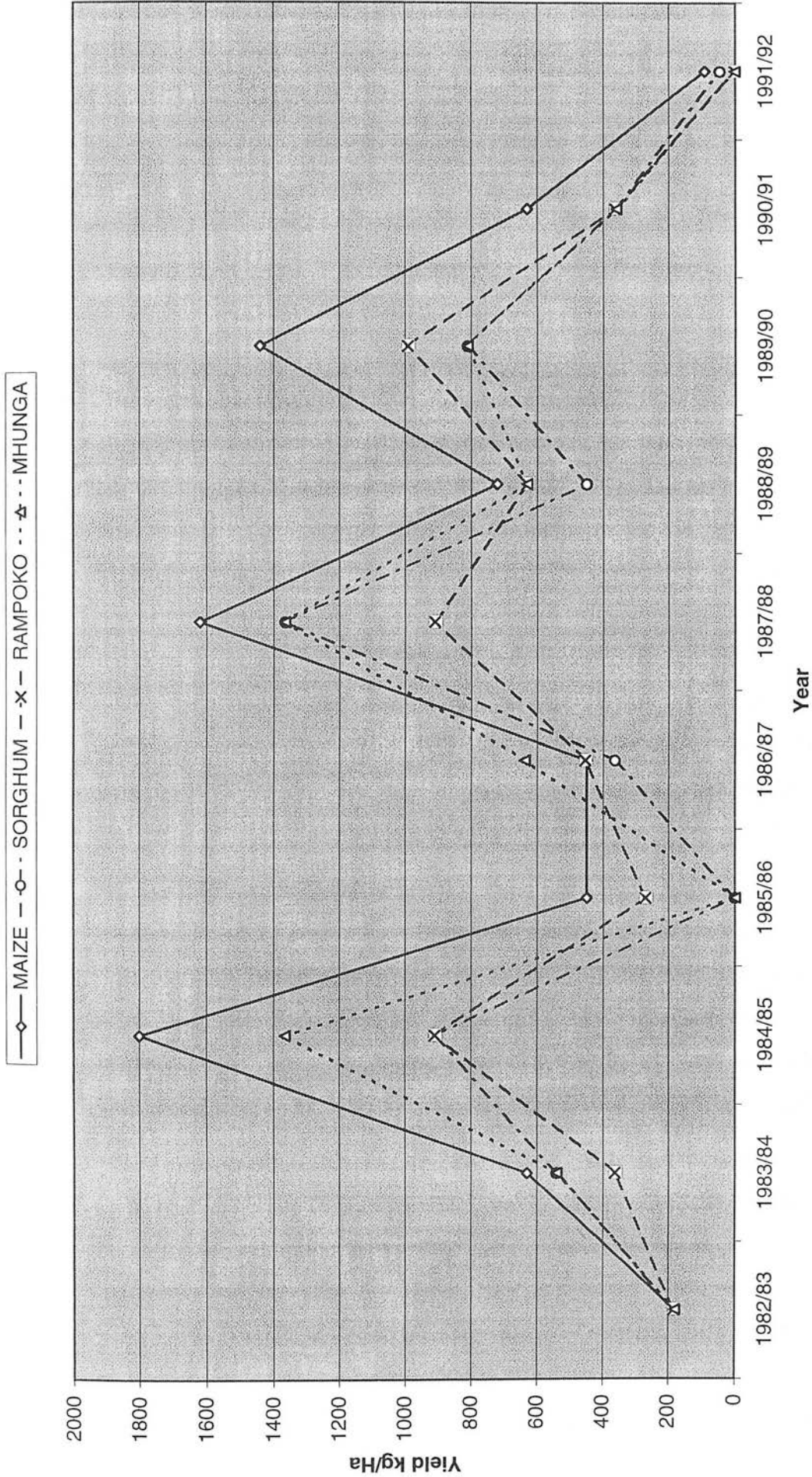


Figure 3.3 Food crop yields for Buhera District for 1982/83 to 1991/92 (Source: Agritex database of crop statistics)

In the previous year, 1993/94, Buhera, like most districts (including those in the commercial farming areas to the north of Harare) had suffered severe droughts with consequentially minimal yields. Other countries in the Southern African Development Community were similarly affected and substantial external food aid was provided to lessen the impacts of food shortages regionally.

For the various survey rounds, the contemporary report to the European Commission (Gundry and Ferro-Luzzi 1996), gives the following summaries of results:

- **‘Demographic (October 1994)** - the average sample household size was 5.6, slightly above the 1992 census size for Buhera of 5.2, with 48% of the population aged 15 years or less (1992 census: 53%). The male to female adult ratio was 0.63 (1992 census: 0.72). Anthropometric rounds, later in the year, highlighted variations in this ratio, reflecting the seasonal changes in agricultural activities and the search for/return from employment away from the home. The demographic survey also collected data about the household environment and the two principal factors: toilet facilities (69% had no facility) and energy source for cooking (99% used wood/charcoal), compared closely with the 1992 census. Housing comprised 2.6 units on average, with walls of clay brick or mud construction and a thatch or corrugated sheet roof.’
- **‘Household assets (October 1994)** - whilst blankets were owned by most households (96%), ownership of furniture was low: chairs (46%), tables (33%). One quarter of households owned a radio and 3% had televisions. However, most households had at least one minor agricultural asset (hoe, axe, sickle or shovel) and 70% owned a plough, suggesting that draught hire was widespread. Two wheeled open carts (‘Scotch carts’) were owned by 17% of households.’
- **‘Food consumption (November 1994, March, July and November 1995)** - by a combination of 24 hour recall (to provide semi-quantitative estimates of household consumption for one day) and frequency of consumption (to provide qualitative data on variability of diet), each carried out four times during the year, it was possible to derive broad estimates of quantity and type of food consumed, including the seasonal variability therein. The usual pattern was three meals per day, although in March and July one third of households

reported only two meals daily. Diet consisted principally of maize meal ('*sadza*') with a vegetable relish. Meat consumption was very low, with less than 10% of households reporting its consumption during the recall period - surprisingly, 5% of households reported eating small fish from Lake Kariba ('*matemba*'), about 1200 km. away. Milk, either fresh or soured ('*lacto*') was consumed by 49% of households in March and about 35% in later rounds. During July, green vegetable consumption was highest (42% of households), falling sharply to 13% in November and 8% in March.'

- **'Health status (November 1994, March, July and November 1995)** - was assessed by questionnaire to the senior female member to establish morbidity by age and sex, impact upon capacity for work and access to healthcare. About 15% of the sample population were classified as sick in the fortnight prior to the survey round. On average, respondents were sick for 7.7 days, of which 2.1 days prevented paid work or school (men and children) and 2.8 days prevented domestic chores (women). Affliction or disease prevalence varied between rounds, although headaches, diarrhoea and stomach problems predominated followed by colds/flu and coughs, although incidence of these was skewed to the winter months. Infectious diseases such as measles and malaria had low incidence in the survey. About one quarter of households had used health clinics in the fortnight prior to each round, 71% attending for cure of ill health, 17% for preventative measures and the remainder for infant or maternity care or monitoring. Travel time averaged 2.7 hours, usually on foot. The principal reason for non-attendance at clinics (cited by 40% of respondents) was lack of funds or distance. Traditional or religious healers had been consulted by 15%. Distribution of health and/or nutrition information appears to be good with more than half the households reporting receiving useful information from the village health worker (40%), the clinics and outreach centres (20%).'
- **'Anthropometric survey (November 1994, March, July and November 1995)** - standard anthropometry techniques of body weight, height and M.U.A.C. (mid-upper arm circumference) measurement for all respondents were carried out four times to identify seasonal variation. Whilst the expectation was that the incidence of reduced nutritional status amongst all household members would be broadly comparable i.e. all family members

would be similarly affected in times of hardship, the survey results show a high incidence of normal to overweight women (body mass index ('B.M.I.') greater than 25), whereas men are generally at the lower end of normal, with a B.M.I. of approximately 20. Children exhibit evidence of both acute and chronic malnutrition, with high prevalence of stunting in 4-5 year olds. Wasting in all children was around 20%, depending on time of year. The sharp difference in nutritional status between women and other household members is unexplained, but the research team is doubtful that it is associated with biased intra household food distribution. The other unusual preliminary finding is that spatial variability of malnutrition in Buhera appears not to be directly correlated with agricultural production potential - northern wards, which are in the better agro-ecological zones seem to exhibit poorer nutrition than those in the south, where soils are poor and rainfall low and variable. However, detailed statistical analysis is required to determine whether such anomalies are the result of geographical variation in age/sex structure.'

- **'Food flows, crops and off farm income (February, June and October 1995)** - with an average of 2.2 hectares of unirrigated farmland and 0.5 hectares of gardens, households in the sample varied their cropping patterns to suit agro-ecological conditions. Southern households, in the drier less fertile zone V, planted more drought resistant crops (e.g. finger and pearl millet, sorghum) and reduced the area under maize. Yields reported for both grains and vegetables were also in line with agro-ecological zoning and agreed well with Agritex (the government's agricultural extension service) estimates. Own produced food supplies were supplemented primarily (56% of households) by purchases from either the Grain Marketing Board (G.M.B.) depot if it was located nearby, or from traders if more remote. Only 12% of households reported grain sales, suggesting that there was a severe shortage in the Buhera District as a whole, which agrees with informal reports from Agritex and the G.M.B.. A larger proportion of households used their own produced grain and groundnuts for brewing and processing to peanut butter, than for sale to outsiders. Food aid was an important contribution to other sources of food inflows, reported by 12% of households. The high level of purchases was funded mainly by remittances from men working away from home in urban areas, with a higher

dependence on such sources in the more remote areas, possibly because opportunities for local casual employment or trading are reduced. Income from livestock keeping seemed low but in line with other surveys, but value of home consumed products and indirect benefits have not yet been assessed.'

Detailed analyses of the data from the primary survey have been carried out by other researchers within the collaborative research project and will not be reported herein. In general, these analyses are the bases for the development of detailed sub-models to be incorporated by users within implemented simulation models. However, the summary results and the general understandings gained from the field survey provided guidance to the design of the overall structure of the framework.

3.7 Analysis of spatial and temporal variability

A premise of this work is that temporal and spatial variabilities are exhibited in the processes underlying the food system and hence in the nutritional status of the population. To establish whether such variabilities are present in the collected data, a restricted analysis of the information from household survey has been carried out by the author and this is summarised below.

A series of simple Chi-squared tests has been carried out on the collected data to establish the spatial variability, as between the three agro-ecological zones, and the temporal variability, as between the survey rounds. The following paragraphs and related tables present an overview of the results. The analyses have been carried out using Chi-squared tests, as follows:

- For **spatial dependency** the observed data were categorised into two groups e.g. cattle / no cattle (the rows of a 2 x 3 matrix) and aggregated by agro-ecological zone (the columns of the 2 x 3 matrix).
- For **temporal dependency**, two categories were again created for the observed data e.g. Malnourished / Not malnourished, but aggregated by round. As the number of survey rounds varied between two and four, determined by the data selected, this produced matrices with two, three or four columns.

For all matrices created, expected values assuming a null hypothesis of independence were then calculated to produce a second matrix. The square of the difference between the expected and observed value, divided by the expected value was calculated for each element in the two matrices to provide a third Chi-square matrix. The sum of the elements of this matrix represents the Chi-squared value for the data. The Chi-squared value is then compared to the tabulated values of the Chi square distribution for 90%, 95% and 99% confidence intervals using the appropriate number of degrees of freedom. For the matrices herein, this is $(R-1) \times (C-1)$, where R and C are the number of rows and columns in the matrix. The summary results for the Chi-squared tests are set out in the tables in the next two sections.

3.7.1 Spatial variability - results

♦ Agriculture

The data reviewed include crop area, cropping patterns, livestock holdings and ownership and use of various agricultural inputs. As expected, Table 3.7 below shows that crop areas and patterns are zone dependent, as is ownership of cattle and hiring of labour. Use of fertiliser is zone dependent in the 1994/95 season only, with no significant dependence in 1995/96 due possibly to most households throughout the district being unable to afford fertiliser following the drought. These dependencies reflect more intensive arable farming in zone III, with higher than expected cattle numbers possibly associated with their use for draught. Note that the other livestock classes, goats and chickens are independent of zone, as is ownership of the major equipment, ploughs and scotch carts. (N.B. although irrigation is zone dependent, this is to be expected as the only one ward, in zone V, has a large-scale irrigation scheme.

♦ Income and expenditure

The data presented in Table 3.8 include both on and off farm income sources. Expenditure data include agricultural and non-agricultural purchases. The numbers of wage earners in the household and off farm income are zone dependent.

Agriculture		CHI SQ@90%	CHI SQ@95%	CHI SQ@99%
Cut-off values, with 2				
degrees of freedom:		4.61	5.99	9.21
	CHI SQ	Dependent on zone?		
Crop Area 93-94	12.62	Yes	Yes	Yes
Crop Area 94-95	12.58	Yes	Yes	Yes
Crop Area 95-96	47.11	Yes	Yes	Yes
Maize% 93-94	107.94	Yes	Yes	Yes
Maize% 94-95	92.50	Yes	Yes	Yes
Maize% 95-96	32.26	Yes	Yes	Yes
Small Grains% 93-94	90.28	Yes	Yes	Yes
Small Grains% 94-95	87.60	Yes	Yes	Yes
Small Grains% 95-96	62.78	Yes	Yes	Yes
Cattle Feb95	9.68	Yes	Yes	Yes
Cattle Jun95	8.69	Yes	Yes	No
Cattle Oct95	7.50	Yes	Yes	No
Goats Feb95	5.18	Yes	No	No
Goats Jun95	5.53	Yes	No	No
Goats Oct95	1.09	No	No	No
Chickens Feb95	0.95	No	No	No
Chickens Jun95	0.28	No	No	No
Chickens Oct95	3.89	No	No	No
Fertiliser 94-95	44.92	Yes	Yes	Yes
Fertiliser 95-96	4.28	No	No	No
Irrigation	14.93	Yes	Yes	Yes
Plough Oct94	1.42	No	No	No
Plough Oct95	3.15	No	No	No
Scotch Cart Oct94	1.99	No	No	No
Scotch Cart Oct95	4.19	No	No	No
Use Hired Labour	7.45	Yes	Yes	No

Table 3.7 Spatial dependency of agriculture data.

Income & Expenditure		CHI SQ@90%	CHI SQ@95%	CHI SQ@99%
Cut-off values, with 2				
degrees of freedom:		4.61	5.99	9.21
	CHI SQ	Dependent on zone?		
No of Wage Earners	13.32	Yes	Yes	Yes
No in Business	5.62	Yes	No	No
Remittances Feb95	3.49	No	No	No
Remittances Jun95	0.88	No	No	No
Remittances Oct95	5.11	Yes	No	No
Off Farm Inc Nov94	27.61	Yes	Yes	Yes
Off Farm Inc Mar95	6.80	Yes	Yes	No
Off Farm Inc Jul95	7.30	Yes	Yes	No
Other Inc Nov94	3.19	No	No	No
Other Inc Mar95	3.31	No	No	No
Other Inc Jul95	3.31	No	No	No
Crop Sales Feb95	12.73	Yes	Yes	Yes
Crop Sales Jun95	5.33	Yes	No	No
Crop Sales Oct95	1.40	No	No	No
Crop Purch Feb95	9.18	Yes	Yes	No
Crop Purch Jun95	9.54	Yes	Yes	Yes
Crop Purch Oct95	5.89	Yes	No	No
Livestock Net Feb95	11.80	Yes	Yes	Yes
Livestock Net Jun95	10.26	Yes	Yes	Yes
Livestock Net Oct95	20.14	Yes	Yes	Yes
Food Buy Nov94	5.05	Yes	No	No
Food Buy Mar95	4.49	No	No	No
Food Buy Jul95	19.78	Yes	Yes	Yes
Hhold Items Buy Nov94	3.46	No	No	No
Hhold Items Buy Mar95	4.23	No	No	No
Hhold Items Buy Jul95	20.23	Yes	Yes	Yes

Table 3.8 Spatial dependency of income and expenditure data

Traditionally the northern wards of Buhera (mostly zone III) have been grain surplus and the zone dependency in February 1995, immediately before the onset of the poor rains, probably reflects this with higher observed sales in zone III. By later survey rounds, after poor harvest outturn in all zones, this dependence has all but disappeared. Crop purchases show zone dependency at different confidence levels for the three survey rounds, again reflecting the deficit position of southern zones (IV and V). The purchase of food and household items is only zone dependent in July 1995, the detailed analysis showing higher levels in zone III than expected for independence, with lower levels especially in zone IV. Livestock income shows zone dependence at each confidence level in all three survey rounds.

◆ Household resources

In Table 3.9 below, household resources and sundry attributes show zonal dependency for the education level of the household head and wife (first wife, in polygamous households), sanitation, water source and market distance. (Although the last two variables were used as stratifiers for the sample selection, this was below the level of zone and thus it can be assumed that the dependency is not a product of the sample frame design.)

The two variables showing dependency at all three confidence levels, sanitation and market distance, both have higher than expected levels of improved sanitation (Blair facilities) and access to markets (less than 5 km.). Water source quality has zonal dependency at the start of the season i.e. when conditions are dry, with water being drawn from protected wells or boreholes for which zone III is best and zone V worst provided. In March and July, unprotected sources become available and these are in widespread use during and after the rainy season in the three zones, lessening the impact of zonal dependency of the protected sources.

Household Resources		CHI SQ@90%	CHI SQ@95%	CHI SQ@99%
Cut-off values, with 2 degrees of freedom:		4.61	5.99	9.21
	CHI SQ	Dependent on zone?		
Household size	0.53	No	No	No
Households with men	1.14	No	No	No
Sex Hhold Head	1.74	No	No	No
Age Hhold Head	3.51	No	No	No
Educ'n Hhold Head	7.26	Yes	Yes	No
Educ'n Wife	9.03	Yes	Yes	No
Polygamy	3.21	No	No	No
Apostolic Faith	3.79	No	No	No
Sanitation	12.48	Yes	Yes	Yes
Water Source Oct94	6.74	Yes	Yes	No
Water Source Mar95	5.52	Yes	No	No
Water Source Jul95	5.13	Yes	No	No
Market Distance	9.64	Yes	Yes	Yes
Gardens	0.03	No	No	No
Housing Type	1.90	No	No	No
Sleeping Rooms	3.81	No	No	No

Table 3.9 Spatial dependency of household resources data.

◆ Food

From the Table 3.10 below, it can be seen that all food related data shows zonal dependency. In general, households in zone III exhibit higher levels of food stocks and greater diet diversity. More households than expected in Zone IV receive food aid and eat wild food. The number of households in Zone V with high food stocks and high diet variability was lower than expected. Sourcing from wild food was in line with expectations, as was food aid, except in March 1995, when the number of recipients exceeded expectations.

Food		CHI SQ@90%	CHI SQ@95%	CHI SQ@99%
Cut-off values, with 2				
degrees of freedom:		4.61	5.99	9.21
	CHI SQ	Dependent on zone?		
Food Stocks Nov94	36.06	Yes	Yes	Yes
Food Stocks Mar95	38.11	Yes	Yes	Yes
Food Stocks Jul95	30.59	Yes	Yes	Yes
Food Stocks Nov95	15.00	Yes	Yes	Yes
Food Groups Nov94	19.41	Yes	Yes	Yes
Food Groups Mar95	25.62	Yes	Yes	Yes
Food Groups Jul95	4.91	Yes	No	No
Food Groups Nov95	7.11	Yes	Yes	No
Food Aid Nov94	10.59	Yes	Yes	Yes
Food Aid Mar95	25.52	Yes	Yes	Yes
Food Aid Jul95	20.18	Yes	Yes	Yes
Wild Food Nov94	6.47	Yes	Yes	No
Wild Food Mar95	23.83	Yes	Yes	Yes
Wild Food Jul95	5.08	Yes	No	No

Table 3.10 Spatial dependency of food data.

◆ Anthropometry

The nutritional status of individuals was measured by anthropometry, at survey points in each vidco. Attendance is shown in Table 3.11 below. Although the total number of individuals on file is 2,264, this will include those non-resident at the time of one or more anthropometry rounds (e.g. men working in cities). Similarly, the total will include those born and those dying during the survey. After such adjustments, the attendees were not all possible individuals, with absence due to work duties (mainly the cohorts of men, young men and boys) and sickness (particularly the elderly cohort). As the survey progressed, some reduction in attendance can also be seen,

despite all households completing the survey being given a bag of 'karpenta' (the dried small fish from Lake Kariba), as thanks for their involvement).

Round	Month	No. attending	% attendance
1	March 1995	1,670	73.8%
2	July 1995	1,593	70.4%
3	November 1995	1,504	66.4%
Total		4,767	70.2%

Table 3.11 Attendance at each of three anthropometry rounds

For the purposes of the Chi-squared analyses of temporal and spatial variability, the anthropometry data have been used without restricting the sample to individuals measured at every round.

Anthropometry#1		CHI SQ @90%	CHI SQ @95%	CHI SQ @99%	Sample size
Cut-off values, with 2 degrees of freedom:		4.61	5.99	9.21	
	CHI SQ	Dependent on zone?			
Under 5's	0.02	No	No	No	764
Children 5-9.9	2.03	No	No	No	987
Boys 10-14.9	0.71	No	No	No	487
Girls 10-14.9	4.66	Yes	No	No	541
Young Men 15-21.9	1.14	No	No	No	268
Young Women 15-21.9	3.72	No	No	No	298
Adult Men	10.15	Yes	Yes	Yes	248
Adult Women	1.64	No	No	No	682
Elderly	28.69	Yes	Yes	Yes	492
					4767

Table 3.12 Spatial dependency of anthropometric data, using cut-off points for 'Malnourished' of 2 standard deviations from international reference means.

The first Chi-squared analysis categorised the age cohorts into Malnourished / Not Malnourished on the basis of cut off points at two standard deviations from means of international reference data, as shown in Table 3.12 above.

It can be seen that zonal dependency is highly likely in the nutritional status of adult men and the elderly. However, the Malnourished observed counts are low single figures for all cohorts except elderly. This has two implications. Firstly, other than the elderly, there is little prevalence of severe malnutrition in the other age cohorts. Secondly, because these observed counts are so low, the application of Chi-squared tests is not valid as expected frequencies for Malnourished for all of the cohorts are less than five for most survey rounds (see Clarke G.M. and Cooke D. (1998) or any elementary statistics book).

Anthropometry#2		CHI SQ @90%	CHI SQ @95%	CHI SQ @99%	Sample size
Cut-off values, with 2 degrees of freedom:		4.61	5.99	9.21	
	CHI SQ	Dependent on zone?			
Under 5's	7.04	Yes	Yes	No	764
Children 5-9.9	17.15	Yes	Yes	Yes	987
Boys 10-14.9	0.71	No	No	No	487
Girls 10-14.9	4.66	Yes	No	No	541
Young Men 15-21.9	1.14	No	No	No	268
Young Women 15-21.9	3.72	No	No	No	298
Adult Men	10.15	Yes	Yes	Yes	248
Adult Women	1.64	No	No	No	682
Elderly	28.69	Yes	Yes	Yes	492
					4767

Table 3.13 Spatial dependency of anthropometric data, using cut-off points for 'Malnourished' of 1 standard deviation from international reference means for Under 5's and Children 5-9.9, otherwise 2 standard deviations as table 3.12 above.

To address this, the Chi-squared analyses were reworked for Under-5's and Children 5-9.9 using a cut-off point of one standard deviation from the international reference mean. This gives the amended values of Chi-squared, as shown in Table 3.13, for those two cohorts.

It can be seen from Table 3.13 that zonal dependency does exist for the nutritional status of Under 5's and Children 5-9.9. Adjusted cut-off points for the other cohorts have not been applied as these are less easy to derive. However, it does appear that for the three cohorts (Under 5's , Children 5-9.9 and Elderly) where the Chi-squared test has been properly applied, nutritional status is zonally dependent. This dependence is exhibited as higher than expected incidence of poor nutritional status in zone III. This result seems counter-intuitive given the generally higher agricultural performance of this zone and the better household characteristics.

In order to examine further the spatial dependency of the anthropometric data, additional Chi-squared tests were carried out to compare the two youngest cohorts across the sample wards, within each of the three zones. In these tests, the observed data for each cohort were categorised into two groups i.e. Malnourished / Not malnourished (using one standard deviation from international reference means) and aggregated by zone. The results of these tests are shown in Table 3.14 below.

Anthropometry#3		CHI SQ	CHI SQ	CHI SQ	Sample
		@90%	@95%	@99%	size
Zone III					
Cut-off values, with 2		4.61	5.99	9.21	
degrees of freedom:					
	CHI SQ	Dependent on ward?			
Under 5's	7.29	Yes	Yes	No	176
Children 5-9.9	4.42	No	No	No	291
Zone IV					
Cut-off values, with 3		6.25	7.81	11.34	
degrees of freedom:					
	CHI SQ	Dependent on ward?			
Under 5's	8.99	Yes	Yes	No	334
Children 5-9.9	9.23	Yes	Yes	No	399
Zone V					
Cut-off values, with 2		4.61	5.99	9.21	
degrees of freedom:					
	CHI SQ	Dependent on ward?			
Under 5's	1.44	No	No	No	254
Children 5-9.9	4.42	No	No	No	297
					1751

Table 3.14 Spatial dependency of anthropometric data, by ward within zone, using cut-off points for 'Malnourished' of 1 standard deviation from international reference means for Under 5's and Children 5-9.9.

Although table 3.13 showed that there is zonal dependency for the nutritional status of the two youngest cohorts, table 3.14 shows that intra-zonal ward dependency for both cohorts is confined to zone IV (at 95% confidence). In zone III, ward dependency is significant (at 95% confidence) only for the Under 5's. This suggests that within the two smaller zones, the influences upon nutritional status vary little across the zone, but that in zone IV some variability exists.

3.7.2 Temporal variability - results

♦ **Agriculture, income and expenditure, household resources and food**

The table below shows temporal dependency for variables other than nutritional status. Note that Crop Area, Maize Percentage and Small Grains Percentage are analysed over the three seasons 1993/94, 1994/95 and 1995/96 and not across survey rounds. Fertiliser use, ownership of a plough and ownership of a scotch cart are also seasonally analysed, but for the last two seasons only. Temporal dependency exists in most arable agricultural variables, with some temporal dependency in livestock. The former is expected, given the seasonal nature of the activity, but it is of note that whilst the number of households planting in excess of 50% maize is dependent upon season, the number planting in excess of 50% small grains does not show the same dependency. This may reflect the risk-reward status of the two crops – maize, potentially high yielding, but risky and small grains, low yielding but reliable. Temporal dependency appears to be present for households owning livestock. Chicken owning households are less numerous post harvest and this may indicate a complementary income stream or food source to the arable production.

Although numbers of households in receipt of remittances and in receipt of off farm income show no temporal dependency, other income from casual employment does depend upon round, at the 95% confidence level. Expenditure shows temporal dependency, probably reflecting the 'lumpy' nature of cash receipts associated with arable farming and thus the household's ability to make purchases at any given point in the year. There are few formal sources of credit available to subsistence farmers,

although there was some evidence of borrowing (principally food) from neighbours and extended family members in times of food stress.

Food stocks and diet diversity exhibit temporal dependency and this is in line with expectations, given the reliance of most households upon subsistence agriculture as the source of a substantial proportion of the family's food.

The number of households with access to protected water also varies with survey round, reflecting the rain dependent nature of many of the sources available.

Household attributes		CHI SQ@90%	CHI SQ@95%	CHI SQ@99%
	CHI SQ	Dependent on round/season?		
Cut-off, with 2 d.o.f.		4.61	5.99	9.21
Remittances	2.26	No	No	No
Off Farm Income	4.22	No	No	No
Other Income	8.77	Yes	Yes	No
Crop Sales	20.82	Yes	Yes	Yes
Crop Purchases	27.92	Yes	Yes	Yes
Livestock Net Income	12.80	Yes	Yes	Yes
Food Buy	15.04	Yes	Yes	Yes
Household Items Buy	23.13	Yes	Yes	Yes
Crop Area	28.09	Yes	Yes	Yes
Maize percentage	21.53	Yes	Yes	Yes
Small Grains %	2.43	No	No	No
Cattle	5.17	Yes	No	No
Goats	3.72	No	No	No
Chickens	8.12	Yes	Yes	No
Water Source	10.26	Yes	Yes	Yes
Food Aid	16.40	Yes	Yes	Yes
Wild Food	52.48	Yes	Yes	Yes
Cut-off, with 3 d.o.f.		6.25	7.81	11.34
Food Stocks	19.86	Yes	Yes	Yes
Food Groups	21.14	Yes	Yes	Yes
Cut-off, with 1 d.o.f.		2.71	3.84	6.63
Fertiliser	60.15	Yes	Yes	Yes
Plough	16.23	Yes	Yes	Yes
Scotch Cart	2.37	No	No	No

Table 3.15 Temporal dependency of household attribute data

◆ Anthropometry

The results of applying the Chi-squared test to temporal dependency in these data are shown in Table 3.16 below.

Anthropometry#1		CHI SQ @90%	CHI SQ @95%	CHI SQ @99%	Sample size
Cut-off values, with 2 degrees of freedom:		4.61	5.99	9.21	
	CHI SQ	Dependent on round/season?			
Under 5's	1.71	No	No	No	764
Children 5-9.9	0.32	No	No	No	987
Boys 10-14.9	2.25	No	No	No	487
Girls 10-14.9	0.43	No	No	No	541
Young Men 15-21.9	1.62	No	No	No	268
Young Women 15-21.9	0.99	No	No	No	298
Adult Men	0.29	No	No	No	248
Adult Women	12.23	Yes	Yes	Yes	682
Elderly	5.15	Yes	No	No	492
					4767

Table 3.16 Temporal dependency of anthropometric data, using cut-off points for 'Malnourished' of 2 standard deviations from international reference means.

Not surprisingly, similar problems to those encountered in the analysis of spatial dependency arose i.e. expected frequencies for all cohorts, other than Elderly, were below 5 using a two standard deviation cut-off point for malnutrition. As with the spatial dependency analysis, the tests were re-worked for Under 5's and Children 5-9.9 and these results are shown in Table 3.17 below. They suggest some temporal dependency, with numbers of individuals with exhibiting poor nutritional status during 1995 being higher in March and November than in July. Given that March is pre-harvest and November is traditionally regarded as the 'lean season', these results are expected. Although the Adult Women cohort also has single figure expected frequencies, none is below 5. The tabulated result of temporal dependence for this

cohort is therefore valid, with numbers malnourished being significantly higher than expected in the November survey round.

Anthropometry#2		CHI SQ @90%	CHI SQ @95%	CHI SQ @99%	Sample size
Cut-off values, with 2 degrees of freedom:					
	CHI SQ	Dependent on round/season?			
Under 5's	6.83	Yes	Yes	No	764
Children 5-9.9	7.10	Yes	Yes	No	987
Boys 10-14.9	2.25	No	No	No	487
Girls 10-14.9	0.43	No	No	No	541
Young Men 15-21.9	1.62	No	No	No	268
Young Women 15-21.9	0.99	No	No	No	298
Adult Men	0.29	No	No	No	248
Adult Women	12.23	Yes	Yes	Yes	682
Elderly	5.15	Yes	No	No	492
					4767

Table 3.17 Temporal dependency of anthropometric data, using cut-off points for 'Malnourished' of 1 standard deviation from international reference means for Under 5's and Children 5-9.9, otherwise 2 standard deviations as Table 3.16 above.

It was noted in section 3.6 that women in the survey appeared to have a better nutritional status than either men or children. Summary analysis of the three survey rounds of anthropometry data is shown in table 3.18 below, with additional gender analysis of cohorts reported.

It will be observed that for both sexes aged under 15 years, the average Weight-for-Age Z-score (i.e. the number of standard deviations away from the mean Weight-for-Age of the international reference population) was below -1 for all cohorts, supporting the preliminary report in 1996, cited in section 3.6. Only three age/sex

cohorts had any overweight members (in all cases only 1%) and these were in the first round of the survey, at a time of relatively plentiful food access.

	Round 1		Round 2		Round 3	
	March 1995		July 1995		November 1995	
<i>Under 15 years of age</i>	WAZ	$\geq +2$	WAZ	$\geq +2$	WAZ	$\geq +2$
Under 5's (Male)	-1.07	1%	-1.09		-1.28	
Under 5's (Female)	-1.12	1%	-1.00		-1.11	
Children 5-9.9 (Male)	-1.14		-1.08		-1.19	
Children 5-9.9 (Female)	-1.04		-1.02		-1.16	
Boys 10-14.9	-1.47	1%	-1.60		-1.59	
Girls 10-14.9	-1.36		-1.34		-1.42	
<i>Over 15 years of age</i>	BMI	≥ 25	BMI	≥ 25	BMI	≥ 25
Young Men 15-21.9	19.0		19.2		19.2	
Young Women 15-21.9	20.8	6%	21.3	8%	21.2	6%
Adult Males	20.6	1%	20.4		20.2	
Adult Females	23.7	30%	23.6	27%	23.1	24%
Elderly (Male)	20.2	5%	20.4	6%	19.5	3%
Elderly (Female)	24.2	36%	24.0	35%	22.9	27%

Table 3.18 Mean nutritional status, by sex, for each age cohort in the three survey rounds. Also shown is percentage of each sex/age cohort classified as overweight at each survey round. (WAZ: Weight-for-Age Z-score, being the number of standard deviations from the international reference population; BMI: Body Mass Index: weight in kilos divided by the square of height in metres).

For those aged 15 years and over, the average Body Mass Index for females exceeded that for males in each of the three age cohorts. It will be noted that the difference increases with increasing age. Furthermore, adult and elderly age cohorts had high prevalence of overweight females, in all three survey rounds.

No explanation has yet been forthcoming for this sharp difference in nutritional status, although local nutritionists suggested that with increased numbers of funerals due to AIDS etc., women were consuming substantially more than men by virtue of their involvement with the food preparation at such ceremonies. Whilst recent increases in mortality may have produced this surprising side effect, it seems clear that further research is required to establish whether a similar position exists in other African countries. If this gender bias in nutritional status is widespread, it will be necessary to consider why other non-African developing countries do not apparently experience this phenomenon.

3.8 Remarks

This chapter has shown that the household survey and the related anthropometry contribute to achieving sub-objective 2: *'To obtain, either by field survey or from secondary sources, sufficient data to characterise adequately household and community resources and analyse the effects of external factors'*.

The results of the Chi-squared tests confirm spatial and temporal variability in household resources and nutritional status, albeit that the variabilities of the latter seem to be restricted to the youngest two cohorts and elderly, with some spatial variability amongst adult men and temporal variability amongst adult women. As noted at the outset of this chapter the breadth of data collected was, with hindsight, excessive for the sole purpose of building the sub-models. However, the comprehensive data provided an insight into behaviour as it influenced nutrition and gave all the researchers involved in the project a better understanding of the problem context.

4 Secondary data sources

4.1 Purpose

There are two purposes of this chapter, which reviews the national and district-level secondary data that have been obtained from sources outwith the collaborative research project. Firstly, to describe the secondary data that provide additional information to characterise household and community resources and, after analysis, support the development of sub-models. Secondly, to review how the modelling framework can facilitate the use of secondary data, minimising the need to carry out primary surveys in order to implement models in new locations. Some secondary data will provide direct input to the implemented models, whilst other data will form the basis of extrapolated input files, such as population and rainfall. The idea of an ‘Index of Infrastructural Vulnerability’ is briefly discussed, outlining its make-up and possible use as a proxy for the underlying causes of malnutrition. Its use was not pursued and the reasons for this are given.

4.2 Background

Various secondary data were identified from the literature and from the household survey as having association with the underlying processes causing malnutrition. These data describe either the household and community resources or external environmental factors. Despite some problems of data access, information was obtained in the following areas and transferred to a project G.I.S., translating the data, where necessary, to a common spatial reference frame:

- Location and climate;
- Infrastructure;
- Demography and socio-economics;
- Agriculture;
- Food aid;
- Health and nutrition;

- Satellite images of rainfall and crop growth.

Data collected for each of these areas are described below, with a summary of the analysis carried out and the use to which the results were put i.e. for sub-model development or as input, directly or indirectly, to the implemented model. Two proprietary packages are in use within the collaborative project: a raster G.I.S. for secondary data analysis and a vector G.I.S. for further analysis and display of both primary and secondary data. A utility has been written to link the two packages. In addition to pre-processing of secondary data, G.I.S. forms a component of the output module of the modelling framework, being used for display of standard reports and response to *ad hoc* queries posed by users. The existence of the data and its coverage and availability influenced the design of the modelling framework. This influence upon the framework design is also summarised below.

4.3 Location and climate

These data were used to provide the background locational information within the project G.I.S. and as such became the spatial reference frame for the analyses of the other secondary datasets.

4.3.1 Digital Chart of the World (National):

Description: The Digital Chart of the World (D.C.W.) is produced by the U.S. Department of Defense and contains the following map layers for Zimbabwe: roads; transport infra-structure (bridges, tunnels, etc.); major settlements; railways, international boundaries; 100-metre interval contours and spot heights; rivers; and other drainage features.

Use: The usefulness of the D.C.W. data is restricted in that most of the source maps used in its compilation are at 1: 1,000,000 scale or coarser and the Zimbabwean source maps are pre-independence and therefore out of date. However, the D.C.W. remains a useful source of information for map layers that do not change (e.g. international boundaries) or change slowly over time (e.g. major river courses). Major rivers are relevant to analysis of access-to-infrastructure within Buhera District

as during wet seasons they effectively form an impassable barrier for most forms of transport.

4.3.2 Contours and Spot Heights (District):

Description: Contours and spot heights were digitised from 1:250,000 pre-independence maps of Buhera from the Department of the Surveyor-General.

Use: To create a Digital Terrain Model of the district with a 250 by 250 metre grid square resolution within the project G.I.S.. This will support three sub-model developments: a rainfall model by ward; an algorithm which assesses households ability to visit clinics, markets etc. and a crop growth model, where elevation is an important variable in determining soil moisture.

4.3.3 Major Soil Types (District):

Description: A 1:250,000 scale map of major soil types within the district was provided by Agritex, Mutare and digitised.

Use: For the development of, and as input to, crop growth models used to simulate farmers' harvest expectations throughout the season.

4.3.4 Agro-Ecological Zones (National):

Description: Agro-ecological zones were digitised from a 1:1,000,000 scale map of Zimbabwe obtained from the Department of the Surveyor-General. Zimbabwe is divided into five main agro-ecological zones that are based on a combination of soil type, climate, vegetation, and land use.

Use: For the development of, and as input to, crop growth models used to simulate farmers' harvest expectations throughout the season. Additionally, as the agro-ecological zones largely determine type of crops grown and relative harvest yields, they provided important stratifiers for the household survey. Furthermore, zoning was seen as an appropriate choice for one of the hierarchical layers of the final modelling framework.

4.3.5 Locations of Major Meteorological Stations (National):

Description: Locations of approximately 50 major meteorological stations within Zimbabwe were obtained from the National Climatic Data Centre in Ashville, Tennessee, U.S.A. and are accurate to the nearest degree-minute.

Use: The final modelling framework includes a ‘rainfall generator’ to provide input to the crop growth model. This uses the locations of the meteorological stations and historical rainfall values, by *dekad* (approximately a ten day period) throughout each year, to simulate different rainfall scenarios, as requested by model users.

4.4 Infrastructure

These data illustrate the quality and extent of economic and agricultural infrastructure, social services and rural development.

4.4.1 Roads (District):

Description: A 1:250,000 scale road map provided by the District Development Fund was digitised for Buhera District. The map was current as at June 1994 and showed tarmac, primary, secondary, and tertiary roads.

Use: Roads are the primary method of access to the other infrastructural features, with persons travelling by bus, using ‘Scotch carts’ (two wheeled open carts, pulled usually by oxen) or on foot. For features within two km. of the household, especially in remoter areas, access routes will often be directly through the bush. Together with contour information and other geographical features (see above), the roads data enable an access-to-infrastructure algorithm to be implemented within the project and so create indices of access for each infrastructural feature for use in the sub-model development.

4.4.2 Locations of Deep Wells and Boreholes (District):

Description: The locations and functional status of deep wells and boreholes in Buhera District as at June 1994 were obtained from the District Development Fund, Buhera. Grid references were accurate to 100 metres and additional information about depth, yield, and sinking date was also provided.

Use: As noted in the background to this chapter (see above), 1992 Census data was not made available to researchers at an aggregation level below district, for information other than population and number of households. Thus for each ward of the study district, it was necessary to compute an index of access to water, both in terms of water quality (i.e. a protected source, such as borehole or deep well) and in terms of distance.

4.4.3 Sanitation by Ward (District):

Description: Numbers of Blair toilets by ward as at June 1994 have also been obtained from the District Development Fund, Buhera.

Use: For similar reasons to the access to water indices, lack of disaggregated 1992 Census data necessitated the computation of an index of sanitation, by ward. This index is used as input to the sub-models concerned with infection and care in the household.

4.4.4 Locations of Clinics (District):

Description: The locations of proposed and functioning health centres (i.e. clinics, hospitals and outreach centres) as at June 1994 were obtained for Buhera District from the Ministry of Health, Mutare, accurate to the nearest 100 metres.

Use: Access to health facilities is an important factor in assessing a household's level of care. It will have two aspects: economic access to health fees and transport costs (determined by the cash available in the household at any point in time and the priorities for its use) and physical access (determined by the access-to-infrastructure algorithm referred to previously). The analysis of catchments for each health facility is described in detail by Wright (1998), as a pre-cursor to evaluating attendance levels for each facility as a percentage of the population served. This enables cross validation of clinic level morbidity statistics with large scale morbidity surveys for particular illnesses or conditions.

4.4.5 Locations of Growth Points and Business Centres (District):

Description: Locations of 'Growth Points', 'Rural Service Centres' and 'Business Centres' within the district were provided by the District Council and digitised. These were accurate to 100 metres.

Use: These locations attract informal traders and as such offer farmers access to small scale marketing of their produce. Indices of access-to-markets can be computed in much the same way as for other infrastructural features.

4.4.6 School Locations: (District):

Description: Locations of schools were also digitised from the 1:250,000 and 1:50,000 pre-independence maps, although the number and locations of schools also appeared to have changed markedly in the subsequent period.

Use: With a relatively stable population (albeit with much seasonal migration) an index of access-to-schools provides a broad measure of educational level in each ward and can be used to estimate the likelihood of school attendance by children in each household. School attendance has important nutritional influences on children as energy requirements for the journey (almost always on foot) and the lack of a midday meal combine to reduce nutritional status.

4.4.7 Irrigation Schemes (District):

Description: A 1:250,000 map of proposed and existing irrigation schemes within the district was provided by Agritex, Mutare and digitised.

Use: Irrigation schemes in the study district are in one ward only at the southernmost point of Buhera. Where farmers have irrigated fields, the crop growth models referred to above require modification to replace simulated dekadly rainfall values with water availability from the scheme.

4.4.8 Locations of Grain Marketing Board Depots (National):

Description: Locations of Grain Marketing Board (G.M.B.) bag and silo depots were digitised from a 1:2,000,000 scale outline map of Zimbabwe for 1993 provided by the G.M.B., Harare.

Use: In addition to the informal marketing of produce at business centres etc., farmers with cash crops or large surpluses of food crops will transport these to the nearest G.M.B. depot for sale. Conversely, following the liberalisation of grain marketing, G.M.B. depots were encouraged to sell grain locally (rather than ship all purchases to urban millers) and thus those households with shortages can also travel to the depots to purchase from the parastatal rather than traders. The location of depots also influences the price at which traders buy and sell grains.

4.4.9 Diptank Locations (District):

Description: Diptanks are used widely in southern Africa by the government veterinary services to provide preventative treatment of cattle against tsetse fly and

other diseases. Each year, smallholders and subsistence farmers in the catchment area of the diptank are encouraged to bring their animals for treatment, which is usually free of charge. In Zimbabwe, in common with other countries, the veterinary service also take a census of the cattle brought to the facility and question the farmers about other animals (including smallstock) at home. For details of the livestock census data, see 'Agriculture' below. Where available, locations of diptanks were also digitised from the 1:250,000 and 1: 50,000 pre-independence maps, the locations of these appeared to have changed markedly in the subsequent period. Only approximately one third of current, existing diptanks could be located on the pre-independence maps.

Use: In view of the unreliability of these data, they were not used as had been intended i.e. in conjunction with livestock census data from diptanks.

4.5 Demography and socio-economics

These data relate principally to the 1992 Census, the boundaries used and the subsequent small changes made to these boundaries for government reporting purposes.

4.5.1 1992 Census Ward Boundaries (National):

Description: Ward boundaries for the August 1992 census were digitised by the Government of Zimbabwe's Department of Social Welfare, in conjunction with U.S.A.I.D. and the Famine Early Warning System project. Each ward was assigned name and population figures from the published census reports. Each ward also has database entries for land class (based on agricultural holding size to give three types: communal land, small scale commercial farming land and large scale commercial farming land), district and province.

Use: Within the project G.I.S., wards can be merged using these columns to produce national land classification maps by ward, district and province. Whilst the study district of Buhera is wholly communal land (with minor urbanisation in the district capital of Murambinda), the bordering districts within Manicaland have small scale commercial farming in addition to communal lands. Land classification of wards provides a method of populating the simulation database with the correct agricultural households, but as Buhera is homogeneous in this regard, this facility was not implemented.

4.5.2 Village Development Committee ('vidco') boundaries (District):

Description: A 1:250,000 scale map of vidco boundaries from Agritex, Mutare was combined with 1: 50,000 scale sketch maps of vidco boundaries from Agritex, Buhera and digitised.

Use: Shortly after the 1992 Census, some boundaries at sub-ward level were changed for administrative reasons. Agritex, the agricultural extension service, changed to reporting crop data using the new vidco boundaries. These vidcos were merged to give a revised ward map for the district, for comparison with the 1992 census ward map. Within the project G.I.S., it was therefore possible, using standard G.I.S. techniques to transfer data collected under one boundary scheme to the frame of reference of the other scheme.

4.5.3 1992 Census Statistics (National):

Description: As at 1996, the following district-level statistics were available from the 1992 Census reports as mean values or aggregate numbers of households within each district: age-sex structure, fertility, mortality, inter-district migration, percentage of urban population, occupation, economic activity, housing type, sanitation type, type of water supply, distance to water supply and educational level of household head. Information available at ward level was restricted to the total population, sex structure, mean household size and agricultural involvement. As noted in the background to this chapter, the project had sought to obtain from the Central Statistical Office (C.S.O.) detailed household information, on an anonymous basis, but this was not forthcoming and similar data to those available at district level for wards in Buhera District were eventually provided by the C.S.O. in the closing months of the field survey. By this time, the decision had been implemented to obtain more detailed household data by broadening the scope of the questionnaires to respondents.

Use: Despite the fragmentary receipt of 1992 Census data, the project G.I.S. eventually included a full national census summary by district and a full Buhera District summary by ward. These ward data were sourced either from the C.S.O. release to the project or the census report for Manicaland Province, which was issued in 1994 and contained ward summaries of all the socio-economic information previously reported nationally, by district. Their principal use has been to compare

various preliminary statistical models derived from primary data (or other authors' reported models) with derivations from the census data.

4.6 Agriculture

Agricultural statistics have two sources in Zimbabwe. For crops, the Ministry of Lands, Agriculture and Water Development provides production data through the extension service, Agritex. For livestock, data are provided by the government's Department of Veterinary Services.

4.6.1 Crop production, sales and retentions (National):

Description: The headquarters of Agritex in Harare collates the annual crop production, the area planted and the yields for maize, the major small grains, sunflower, groundnuts and cotton. These data are available for the Communal Areas and are based on 10 farms within each ward. The information has been obtained by the project for all Communal Areas (of which Buhera is one) for the period 1981-92. In addition, the same information is available for 1993, but broken down by ward rather than by Communal Area. For the large-scale and small-scale commercial farming sectors, the same information has been obtained by province for the period 1990-93. However, for these sectors production data are available by province only, albeit for a much wider range of crops.

Use: The principal use of these data is to calibrate the crop growth model for yields by comparing model yields under different rainfall scenarios with the historical ward average yields in seasons with similar rainfall. The data also provide an alternative source of yield and area planted for the Buhera wards not surveyed as part of the primary data collection.

4.6.2 Large livestock numbers (National):

Description: Livestock census numbers are available annually for the period 1987 to 1993 from the Department of Veterinary Services, broken down by species and Communal Area. This information is based on interviews with farmers who bring their animals to diptanks. The same information has also been obtained for the small-scale and large-scale commercial farming sectors for the period 1990-91, broken down by province.

Use: It had been hoped to use the diptank census data to provide estimates of livestock by ward and, by extrapolation from the field survey, the number of animals per household in the simulation. However, because of the errors in these diptank data they have not been used further, although future implementations of the model in other countries (or in Zimbabwe after correction of census procedures) would benefit from their use.

4.6.3 Smallstock numbers (District):

Description: The results of a smallstock census undertaken in September 1993 has been obtained from the Department of Veterinary Services, Buhera District broken down by species and diptank.

Use: As with large livestock, it had been hoped to use the diptank smallstock census data to provide estimates of livestock by ward and, by extrapolation from the field survey, the number of animals per household in the simulation. However, because of the errors in these diptank data they also have not been used further, but see 'Large Livestock Numbers' above regarding future use.

4.7 Food aid

Food aid data are difficult to obtain and whilst the operation of assistance schemes often takes place against a background of crisis, monitoring and reporting of operations could be improved and accurate statistics published. The data below was the only source available, although other donors were known to be involved in similar distributions and/or food-for-work programmes.

4.7.1 Requests for food aid, distributions and recipients (National):

Description: The total tonnage of food aid distributed by the Department of Social Welfare, together with the total numbers of people requesting and receiving food aid have been obtained by district for the period 1983-1993.

Use: These data provide an average food aid distribution for each district and thus for Buhera, for simulation households flagged as food aid recipients, the quantity of food received is assumed to be the Buhera District mean. (As no other agency was providing food aid in the study district, no adjustment to the Social Welfare mean is required).

4.8 Health and nutrition

The Government of Zimbabwe's Ministry of Health is responsible for the national network of health facilities: hospitals, clinics and outreach centres. Monthly reporting of morbidity and mortality statistics is by the 'T5 Form' from clinics, collated and summarised at district, province and national level. Additional *ad hoc* health and nutrition surveys can be implemented in response to outbreaks of disease or in times of drought.

4.8.1 T5 Form Data Set (National):

Description: This has been obtained for the period January 1988 to March 1993 from the Ministry of Health, Harare with the help of Department of Social Welfare, in conjunction with the U.S.A.I.D./F.E.W.S. project. The T5 form is a district-level tally sheet that is used to collate monthly summaries of the following statistics: weight-for-age malnutrition in children under-5; low birth weight; chronic and acute diseases; immunisations; maternal deaths and injuries. These data are collected on clinic-level tally sheets and transferred to a district summary form before being computerised at the district office, provincial office or national headquarters.

Use: The national T5 Form data, reporting malnutrition and illnesses by district averages has been used by Wright et al. (1998) to assess the extent of leads and lags in illnesses from one district to another. His work shows that disease spreads outwards from the capital Harare. The data have also been used by Wright (1998) to investigate how the results of the implemented model can be validated to the district level T5 statistics.

4.8.2 T5 Form Data by Clinic (District):

Description: The T5 form data has also been obtained from the Ministry of Health, Buhera by clinic within the district for the period January 1991 to September 1995. The information is monthly and includes: weight-for-age malnutrition in under-5s; low birth weight; chronic and acute diseases (1991-92 only); immunisations and various other maternal and child health information.

Use: Within the modelling framework, the interaction of food access with infection is central to the simulation process. To achieve this, the modelling framework has an

infection sub-model that uses background infection rates, as modulated by each household's socio-economic factors (e.g. access to water, sanitation, education level of mother etc.). These background rates are derived from a combination of the infection rates observed in the household survey and the T5 Form Clinic data. To convert clinic statistics to ward statistics has required the estimation by G.I.S. techniques of each clinic's catchment and hence the equivalent 'T5' statistics by ward can be derived.

4.8.3 1992 Mid-Upper Arm Circumference Survey (National):

Description: This cross-sectional data set, collected by Ministry of Health during the 1992 drought, is available by ward and gives the numbers of under-5s with Mid-Upper Arm Circumference greater than 13.5cm, 12.5-13.5cm, or less than 12.5cm.

Use: In a similar way to the national T5 data, Wright (1998) has investigated how these data might be used to validate the malnutrition rates predicted by the simulation models.

4.9 Satellite images

There has been an increasing use of satellite image data by the various 'early warning' units of governments and international agencies. The F.A.O. is the principal proponent of such data use and has established a network of regional centres, including one in Harare for S.A.D.C.. As noted in the earlier chapters, these systems provide timely notice of major drought events, but are less satisfactory for reporting sporadic drought.

4.9.1 Normalised Difference Vegetation Index (N.D.V.I.) imagery (National):

Description: N.D.V.I. is a measure of vegetation growth and photosynthetic activity derived from the NOAA Advanced Very High Resolution Radiometer (A.V.H.R.R.) satellite. N.D.V.I. is calculated from the reflectance values at the infra-red and red wavelengths, taken directly from the satellite images. It is dimensionless and is calculated using the expression:

$$N.D.V.I. = (R_{IR} - R_R) / (R_{IR} + R_R)$$

Where R_{IR} and R_R are the reflectance values at the infra-red and red wavelengths. The maximum recorded value of this index is available for each ten day period ('*dekad*'). The project holds N.D.V.I. data for Zimbabwe for the period January 1981 to December 1991, obtained through the F.A.O./ARTEMIS image bank.

Use: By using the N.D.V.I. broken down by ward, a simulation model's crop growth estimates (which are modelled at ward level) can be calibrated. Consideration should be given in future versions of the modelling framework to directly interfacing N.D.V.I. results in the early part of the season to the simulation by modelling of the remainder. This would enable rapid predictions of seasonal outturns from satellite observations at an early stage in the growing cycle.

4.9.2 Cold Cloud Duration (C.C.D.) images (National):

Description: Cold Cloud Duration (C.C.D.) images can be used as a proxy measure of convectional rainfall in areas where the surface meteorological station network is sparse (though C.C.D. is not a proxy for orographic or depressional rainfall). Like N.D.V.I., the imagery is derived from the NOAA-AVHRR satellite system and consists of the number of half-hours during which cloud tops fell below -40 degrees centigrade for each *dekad*. The imagery held by the project is for the period October 1988 to September 1995 with a spatial resolution of approximately 7 km. by 7 km. on the ground. The data were obtained through the F.A.O. Regional Early Warning System (R.E.W.S.) in Harare.

Use: As noted above, the crop growth sub-model requires input from a 'rainfall generator' to give precipitation values by *dekad*. This rainfall generator was intended to use C.C.D. imagery to provide ward level estimates. However, the algorithms in use by the United States Geological Survey Africa Data Dissemination Service (who provide interpolated C.C.D.) proved too coarse for deriving such small area estimates. An alternative approach was adopted which used ground station data to simulate rainfall by ward. This is described in section 7.6.1.

4.10 'Index of Infrastructural Vulnerability'

In parallel to the detailed development of the first framework, reported in the next chapter, various factors relating to socio-economic resources and infrastructure had been suggested by the literature as having a long term, slowly changing impact upon

the local food system. These were tabulated, as shown in Table 4.1 below and grouped by major factor and sub-factor.

The aim was to develop an 'Index of Infrastructural Vulnerability' which would act as a proxy for the underlying causes of malnutrition and so limit the modelling framework to the representation of the short term processes. The outcomes of these short term processes would then be used to modulate any given location's vulnerability, as measured by this index.

The table shows those elemental variables for which secondary data had already been obtained and incorporated within the project G.I.S.. For those labelled 'Possible', the secondary data were known to be available, but had not been obtained. Those elements marked 'Expert' within the 'Customs' factor would have required expert assessment to determine their relative locational value.

Two points should be made about the use of such an index. Firstly, because the index is a slowly changing variable, it is robust to the inevitable minor errors, or to differences in frames of reference, which will occur in the underlying secondary data used in its compilation. Secondly, substantial co-ordination of the secondary data sources will be required to provide an onwards flow of information, in the common format required for constructing the index. In particular, this implies consistent levels of aggregation, different from those employed by the data 'owner', which may necessitate additional processing of the data and is likely to be a time consuming and costly exercise. Nonetheless, if successful, such data should provide a level of coverage which is very cost efficient when compared to the commissioning of primary surveys or *ad hoc* comparative analyses of existing primary survey data.

Factor	Sub-factor	Element	G.I.S.?
Socio-economic	Transport	Roads	Yes
		Railways	Possible
		Buses	Possible
		Vehicle ownership	Possible
	Agricultural support	Access and quality of	Yes
		Access to millers	Possible
		Extension services	Yes
		Access to credit	Possible
	Employment	Local non-farming	Possible
		Commercial farms	Possible
Living conditions	Environmental	Education level	Yes
		Access to potable water	Yes
		Sanitation	Yes
	Facilities	Housing	Yes
		Access to hospitals	Yes
		Access to primary care	Yes
	Mortality & morbidity	Drug & medicine	Possible
		Birth & fertility rates	Yes
		Death rates / life expectancy	Yes
		Principal disease statistics	Yes
Demographic	Household size	Number in household	Yes
		Dependency ratio	Yes
		Migrant workers	Yes
	Assets	Landholding	Yes
		Livestock	Yes
	Characteristics	Gender of household head	Yes
		Education of household	Yes
		Access to forests	Yes
Natural	Flora & fauna	Access to rivers, lakes	Yes
		Access to forests	Yes
	Agro-ecological	Soils	Yes
		Rainfall	Yes
		Temperature	Yes
		Topography	Yes
		Pests	Possible
		Access to forests	Yes
Customs	Traditional	Labour allocation on farm	Expert
		Food preparation methods	Expert
	Religious/Tribal	Dietary constraints	Expert
		Animal husbandry practices	Expert
		Polygamy	Yes

Table 4.1 Long term influences on food access and health – possible structure of ‘Index of Infrastructural Vulnerability’

However, although use of this index in the modelling framework was alluring, subsequently the approach was seen to be inconsistent with the development of the systems dynamic framework (which is described in detail in the next chapter). As will be reported, this development involved breaking down the causal processes of the 'malnutrition-infection complex' into its constituent components and sub-components. The use of a broad spectrum index within narrowly focussed sub-components was then judged to be inappropriate. The only solution would have been to re-weight the constituent elements of the index for each sub-component and this was felt to be unsatisfactory and somewhat self-defeating. Further development of the index was therefore not pursued and it has not been used in either of the frameworks that have been developed.

4.11 Remarks

Secondary data collected in Zimbabwe were, until recently, considered to be confidential to the collecting body (usually a government department) and only published, if at all, at high levels of aggregation (typically whole province or district). 'Sharing data' was restricted to non-governmental organisations (N.G.O.s) and researchers. In particular, the 1992 census in Zimbabwe comprised detailed questionnaires about both demography and household socio-economic characteristics and used anonymously would have provided a substantial source of data for the household analyses. Data from this census were held within the Central Statistical Office (C.S.O.). At the outset of the project, the research team, through the collaborating institution the University of Zimbabwe, requested disaggregated anonymous data for Buhera District. However, approval was not given for the release of any unpublished information and this influenced the scope of the household survey. Census data were finally released to the research team in the last three months of the household survey, but even then, the files comprised ward-level means and aggregates rather than detailed household-level data. Similarly, the initial project specification assumed that transaction data from the parastatal Grain Marketing Board (G.M.B.) could be obtained to illustrate the extent of purchases and sales by G.M.B. depots within and close to Buhera District, including details of payments to individual

farmers for grain and cash crops. Release of these data was also blocked, on the grounds of commercial confidentiality.

Although the position as regards release of low level government statistics appears to be relaxing in Zimbabwe, the extent to which similar obstacles may arise in obtaining such data in other developing countries should not be underestimated when considering implementing models of this type elsewhere.

Whilst the 'Index of Infrastructural Vulnerability' was not subsequently used in either of the two modelling frameworks, the idea served to emphasise the importance of differentiating between long and short term effects of the different variables implicated in the causal processes underlying food access and health. Indeed, the second framework – the expert system simulation – takes this idea further by classifying household, ward, zone and district level variables as 'dynamic' or 'static', with static being non-changing over at least one agricultural year.

Notwithstanding the difficulties relating to obtaining the data, the secondary data obtained complement the data collected in the household survey and, in combination, substantially achieve sub-objective 2: *'To obtain, either by field survey or from secondary sources, sufficient data to characterise adequately household and community resources and analyse the effects of external factors'*.

5 Framework I – a systems dynamic approach

5.1 Purpose

This chapter describes the development of the first simulation modelling framework, using a systems dynamic methodology. A framework is constructed to simulate the food system over a period of one year. It takes the UNICEF concept of the ‘malnutrition-infection complex’ as its starting point. In the UNICEF diagram (see Figure 2.2), the two principal causal processes of inadequate dietary intake and disease require amplification to be suitable for incorporation within the modelling framework. Furthermore, there is a need to reconcile the outputs from the two processes to provide a coherent measure of nutritional status. The problems encountered with the use of systems dynamic modelling methodology are discussed, in particular the difficulties associated with multi-level objects and the heterogeneity of the objects at each level. Although the use of this methodology was subsequently discontinued, the core ideas inherent in this prototype were carried through to the second simulation modelling framework.

5.2 The UNICEF diagram of the ‘malnutrition-infection complex’

The UNICEF diagram in Figure 2.2 presents the ‘malnutrition-infection complex’ as four layers. In the topmost layer, malnutrition and death are the *manifestations* of the *immediate causes* – inadequate dietary intake and disease (and their interaction) – that are shown in the second layer. The third layer shows these immediate causes as the results of three *underlying causes*:

- Insufficient household food security;
- Inadequate maternal and child care;
- Insufficient health services and unhealthy environment.

It will be noted that these three underlying causes are represented as overlapping ellipses, implying interaction between them. In the fourth layer, the *basic causes* are

shown as the potential resources, as controlled by the human, economic and organisational structures.

Whilst this diagram may have offered conceptual insight into the policy issues associated with malnutrition, it is vague in its representation of the causal processes involved and it does not directly provide a suitable starting point for the modelling framework. As noted in section 2.7 the diagram makes no reference to different rates of temporal change in the causes. In order to create a more suitable representation of the processes involved, a series of diagrams was developed from the literature, which emphasised the physiological aspects determining an individual's nutritional status. The more detailed diagrams for each of the three contributing factors, taken from Gundry and Ferro-Luzzi. (1994) are enclosed in Appendix IV. The summary diagram is as follows:

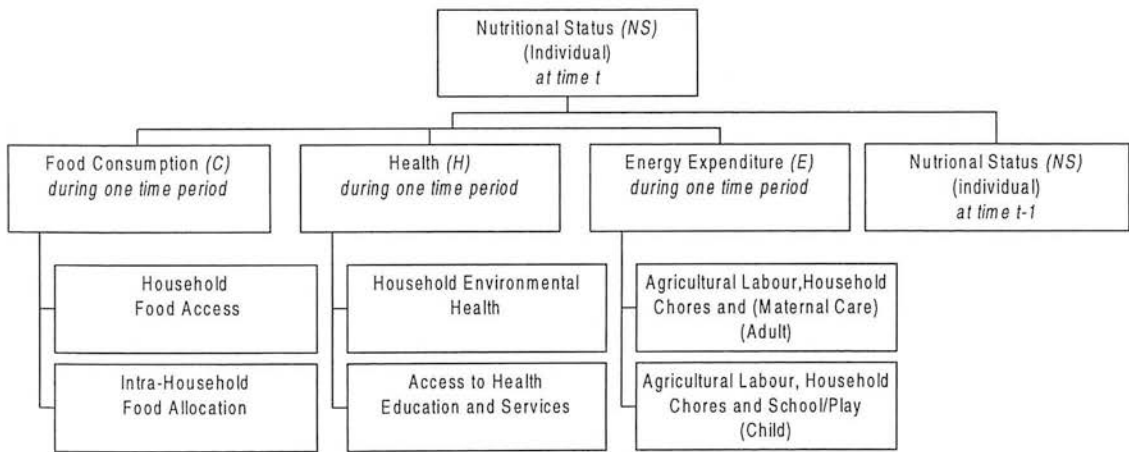


Figure 5.1 Summary diagram of nutritional status.

This diagram explicitly recognises the temporal variability in nutritional status by representing the current state as derived from the previous state, as altered by food consumption, health and energy expenditure during the period.

Expressed formally, this would be:

$$NS_t = NS_{t-\Delta t} + f(C_t, H_t, E_t) * \Delta t$$

Re-arranging and as $\Delta t \Rightarrow 0$ then:

$$\frac{dNS}{dt} = f(C, H, E)$$

The intention here is to show that the rate of change of nutritional status is assumed to be determined by the three variables of food consumption, health and energy (subsequently reduced to two – omitting energy – see below). This is the basis of the separation of the modules for food access and health within the systems dynamic model.

There are two difficulties with Figure 5.1. The first concerns energy expenditure. Undoubtedly the basic physiology of the nutritional process dictates that, given a constant health status, short term change in body weight will only occur if the energy content of the consumed food differs from the energy expended during the same period. However, subsequent discussion of Figure 5.1 with colleagues from the collaborative research project suggested that insufficient data were available to model energy expenditure accurately. It was agreed that a preferable modelling treatment would be to use energy expenditure as input to intra-household food allocation and as an outcome variable of nutritional status, so reducing the principal variables to food and health (as in the UNICEF diagram).

The second difficulty with Figure 5.1 concerns the different temporal variability of the different causes. Some causes will have significant short term variability, whereas the ‘underlying’ and ‘basic’ causes will change more slowly over time.

As a result of these two points and further discussion amongst the collaborative researchers about the detail of the food consumption and health processes, the diagram was re-designed. The revised version is shown in figure 5.2 overleaf.

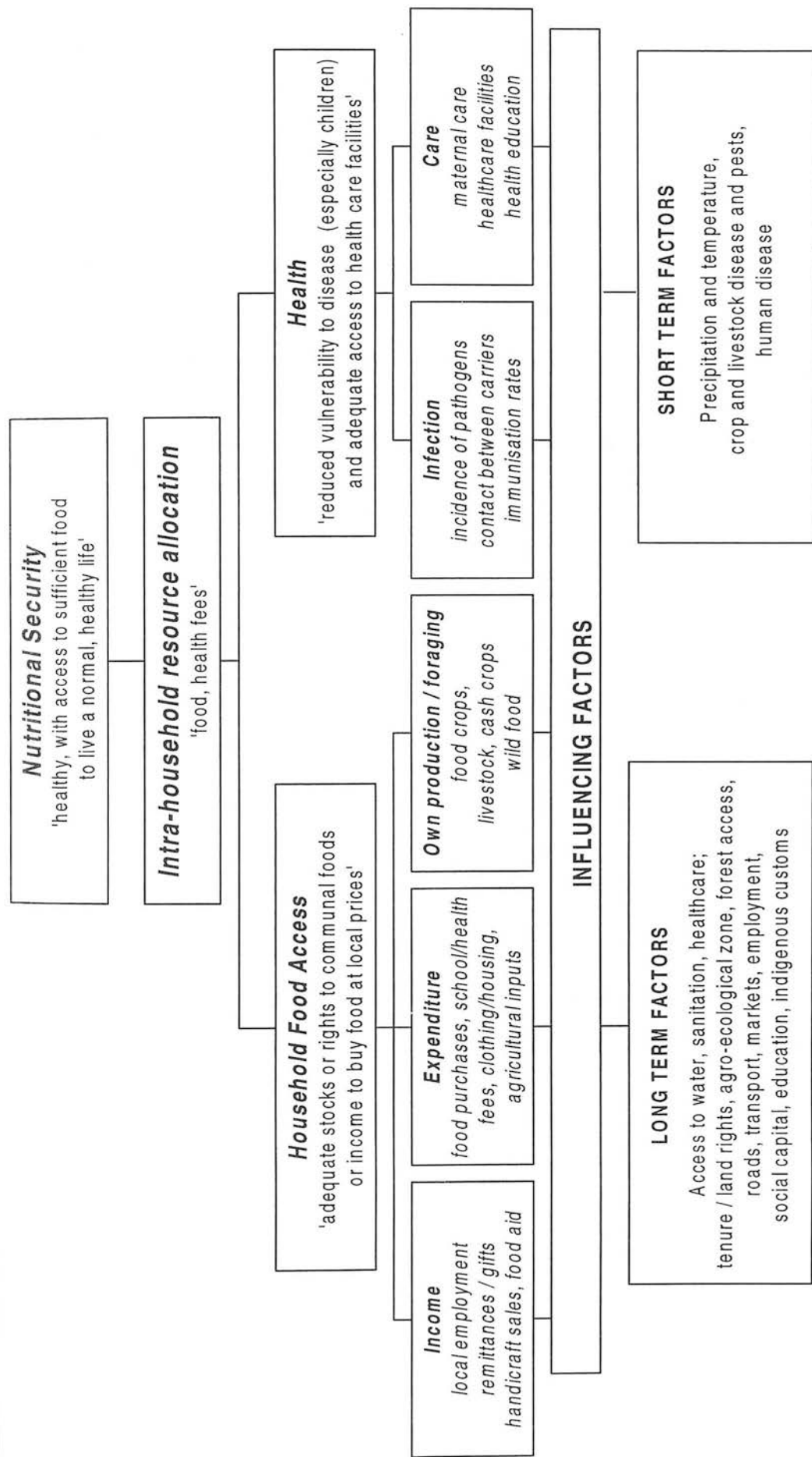


Figure 5.2 Revised conceptual diagram of nutritional security.

Several points will be noted about this revised diagram. Firstly, the two factors food access and health, and their interaction, are seen as the core causal processes. If both of these factors remain at adequate levels, then the outcome will be a 'secure' level of nutritional status. Thus, the diagram uses the broader term of *nutritional security*, to encompass individuals, households or communities.

Secondly, the temporal variabilities in all the causal processes are explicitly recognised by the lower part of the diagram, where various '*influencing factors*' are shown as having either long or short term affects. (Note that this diagram should not be taken to imply that the nutritional state at time t is regarded as independent from the state at time $t-I$, a concept which is retained within this and the successor modelling framework.)

Thirdly, each of the two principal causal factors has been broken down into its components. For food access, there are three sub-factors: income, expenditure and food production. For health, two sub-factors are shown: infection and care. Each of these sub-factors is represented by (at least) one module in the modelling framework. Each module is linked to one or more of the other modules and can be specified, in the dynamic systems modelling language, by mathematical expressions which include the long and short term factors shown.

5.3 Resource stocks, flows and influences

Before describing the versions of the modelling framework that were developed using systems dynamic methodology, it will be helpful to explain the various elements used to represent systems under study.

In systems dynamic modelling methodology, natural, ecological and economic systems are represented as a network of resource stocks, the flows between which are controlled by a one or more mathematical expressions, which can be a differential equations. For each of these flow expressions, reference can be made to the value of the stock of each resource, to the values of other resource stocks or flows and to other variables which *influence* the flow rates. These other variables can be endogenous to the system and linked to other elements within it or can be exogenous, representing

variables outside the system boundaries. Systems are modelled by creating simulation runs with a set number of defined time steps. From the starting conditions for each resource stock the final values of all stocks, flows and variables are calculated. It is also usual to monitor the intermediate values of these.

The validation of systems dynamic models should, in essence, follow the same approach as that for other simulation models. However, because the use of systems dynamic models encourages the representation of the inherent feedback mechanisms in natural systems, additional care must be taken. Oakshott (1997) quotes (p.253) Schlesinger's (1974) definition of validation 'The process of substantiating that the model within its domain of applicability is sufficiently accurate for the intended application'. He observes that this definition remains appropriate today and points out that exact agreement between model and system is not required, rather that it 'should be adequate for its intended purpose'. Oakshott proposes that validation should take place in three stages, as developed by Naylor and Finger (1967) and extended by Law and Kelton (1991). The three stages suggested by Oakshott are:

1. **Face validity** – deciding whether, on the surface, the model seems to behave as expected and produce reasonable results;
2. **Assumption and parameter testing** – analysing the effect of changes in assumptions and parameters (their values and distributions) to assess the sensitivity of the model overall and of the individual sub-models;
3. **Statistical comparison** – analysing the output from a set of randomised simulations to establish the confidence intervals that the model and the individual sub-models are in agreement with the real system.

For the systems dynamic framework developed herein, only the first stage above – face validation – has been presented. This is because the implementation of the individual sub-models within the framework remained the responsibility of colleagues in the collaborative research project and each was therefore responsible for the second and third validation stages. Upon implementation of any particular simulation model, validation would be the collective responsibility of the research team.

There are several commercial implementations of the systems dynamic modelling methodology (e.g. Stella II, ModelMaker), but these usually possess three common features: (1) a graphical user interface to represent the system under study, with different icons for the modelling elements of stocks, flows and variables; (2) a coding interface to enable each element to be represent by a constant or mathematical expression; and (3) an output module to facilitate tabular and graphical results for intermediate and final values of user-selected elements. The developments undertaken herein used the modelling software Stella II and examples of these three features for that software are described briefly below.

In Stella II the main elements of the graphical user interface are shown below:

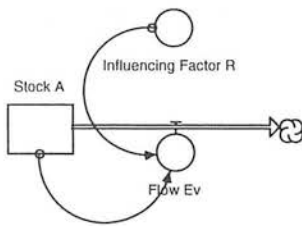


Figure 5.3 Graphical user interface in Stella II

The system depicted in this figure is composed of four types of component: *stocks*, also known as conserved state variables, representing accumulations of resources which can be determined by counting or measuring; *flows*, also known as control variables, which determine the changes in stocks over time; *influencing factors*, also known as non-conserved state variables; and *influences*, shown as curved lines with arrow heads, which represent interactions between the three other types of system component (Hannon and Ruth 1994). The ‘cloud’ icon shown on the right hand side of Figure 5.3 represents the open ‘world’ outside the system under study.

The figure above is a trivial working model of evaporation of a liquid. Assume that ‘*Stock A*’ represents a liquid that evaporates by ‘*Flow Ev*’ to the atmosphere. The atmosphere, being outside the system under study, is represented by the small cloud icon on the right. The icon for the ‘*Flow Ev*’ shows two links (the influences) from ‘*Influencing Factor R*’ and ‘*Stock A*’, to represent the product of the known

percentage evaporation rate for the liquid (*'Influencing Factor R'*) and the quantity of *'Stock A'*.

The coding for this simple example, which assumes at starting quantity of liquid of 100 and an evaporation rate of 5% per hour, is shown below:

```

Stock_A(t) = Stock_A(t - dt) + (- Flow_Ev) * dt
INIT Stock_A = 100
Flow_Ev = Stock_A*Influencing_Factor_R
Influencing_Factor_R = .05

```

For this example, a simulation is run over 100 hours, in time steps of 1 hour. The resultant graphical output, showing the quantity of *'Stock A'* remaining and *'Flow Ev'* is shown below:

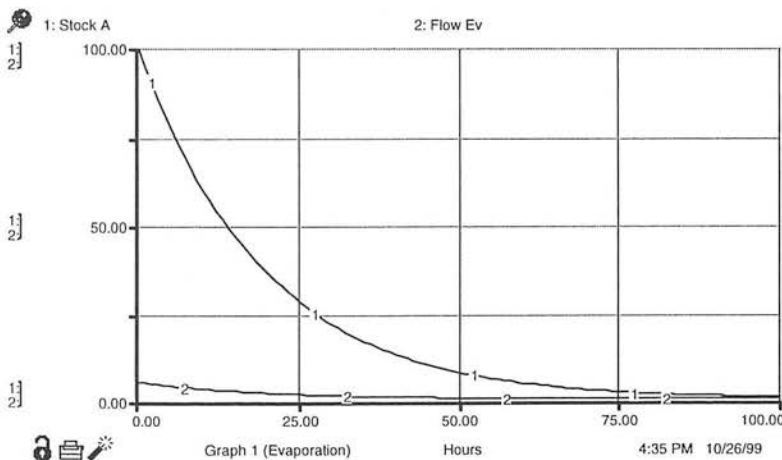
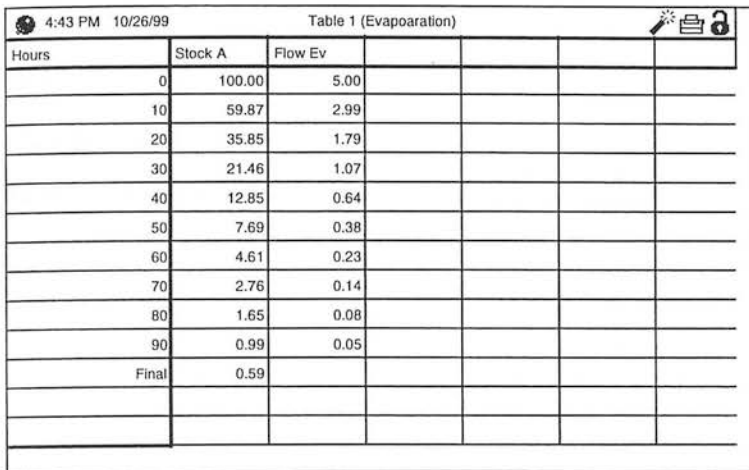


Figure 5.4 Graphical output for Stella II

Alternatively, tabular output can be produced, as follows:



Hours	Stock A	Flow Ev				
0	100.00	5.00				
10	59.87	2.99				
20	35.85	1.79				
30	21.46	1.07				
40	12.85	0.64				
50	7.69	0.38				
60	4.61	0.23				
70	2.76	0.14				
80	1.65	0.08				
90	0.99	0.05				
Final	0.59					

Figure 5.5 Showing tabular output from Stella II

Although this simple example uses trivial mathematical expressions, a wide range of functions is available to enable complex representations to be formulated.

Additionally, the software allows a limited amount of ‘hiding’ of sub-models and contains a facility to abstract the flow diagramming to a higher level of model maps. With this in mind, the software seemed able to offer an ideal platform for constructing a modelling framework for local food systems.

5.4 Nutritional security

From the nutritional security diagram in Figure 5.2, the approach to the first modelling framework was developed by considering the two principal causal processes (food access and health) as separate components. Each of the two components has sub-components: for food access - income, expenditure and own production / foraging; and, for health - infection and care. By creating each of these sub-components, using systems dynamic methodology, it was possible to link each component to the appropriate influencing factors.

This effectively laid down the approach for the lower two layers of the three layered modelling framework, corresponding to the nutritional security diagram. However, the problem remained as to how the second layer components could be coherently linked to produce some measure of nutritional security. The output from Food Access component would almost certainly be denominated in calories or a derivative thereof

(e.g. sufficiency of calories), whereas the output from the health component would be denominated in some sort of morbidity statistics, possibly by illness category.

Reconciling these two differently denominated components was perhaps the most substantial obstacle to progress.

The solution, as originally suggested by a colleague Dr. Robert Muetzelfeldt, was to assess nutritional security for a community on the basis of numbers of individuals in each of four categories: healthy, sick, malnourished and sick-and-malnourished. By categorising the population of each community in this way it was possible to treat each category as a ‘stock’ and model the flows (of discrete individuals) between each category under the influence of changes in levels of food access and changes in sickness and recovery rates. Initially, with a steady state community, the only flows of people to/from the four categories, other than flows between the categories, were births and deaths.

Inevitably, this approach became known as the ‘four box’ method and is illustrated by Figure 5.6 below. This diagram, which has been simplified by omitting births, deaths and influencing factors, represents the population of children within a community.

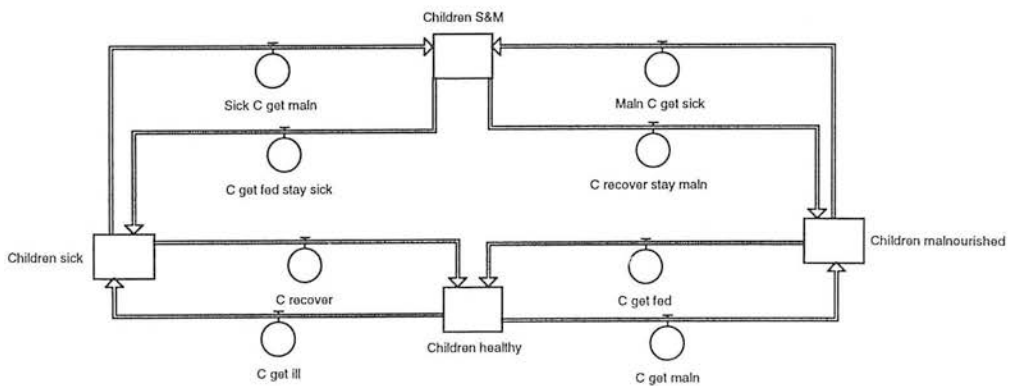


Figure 5.6 The ‘four box’ method of categorising children’s nutritional status

It will be noted that for each of the four boxes there are two inflows and two outflows. For example, from the ‘Children healthy’ box (centre, lower), the flow ‘C get ill’ will transfer children to the ‘Children sick’ category and the ‘C get maln’ flow will transfer children to the ‘Children malnourished’ category. Children are transferred to

the ‘Children healthy’ category by the reverse flows i.e. ‘C recover’ (from the ‘Children sick’ category) and ‘C get fed’ (from the ‘Children malnourished’ category).

The advantage of this ‘four box’ structure is that the outputs for the two causal processes of food access and health did not need to be reconciled, but could be applied directly to the eight flows for each population cohort (children and adults). With this ‘four box’ approach in place in principle, the main perceived obstacle was overcome and the components and sub-components of the modelling framework representing the causal processes could be developed in more detail.

(However, one disadvantage of the ‘four box’ structure is that within each cohort, only four states are possible as derived from the boolean categories sick/not sick and malnourished/not malnourished and degrees of sickness or malnutrition are not modelled.)

For the construction of the systems dynamic framework described below, the influencing factors have been chosen in discussion with colleagues, based on their expert views and any preliminary analyses that they had carried out at that time. Their supporting preliminary analyses are not reported herein. Influences can clearly be broken down further and the framework is designed to allow (and encourage) such decomposition by individual modellers, as necessary to represent accurately the studied subsystem.

5.5 Food access

The Food Access component of the modelling framework presented herein is based upon a single subsistence farming household. With reference to Figure 5.2, the first principal component of nutritional security, food access, is shown as having three sub-components: income, expenditure and food production. The first two of these are concerned with cash and thus the section of the modelling framework for income and expenditure will be denominated in local currency, which for Zimbabwe, is Zimbabwean Dollars. The other sub-component, food production / foraging, relates primarily to subsistence agricultural activity, which in Zimbabwe will predominantly

be a mix of arable crop production and livestock keeping. For arable crop production the most appropriate denomination will be in terms of the principal staple, maize and thus this section of the Food Access component is denominated in ‘kilograms of maize equivalents’, where quantities of other crops are translated to maize equivalents based on calorific values. For livestock, either chickens or goats would be suitable as a denomination for all livestock kept (usually one or more of chickens, goats and cattle) and goats were selected. Thus all livestock are expressed in ‘goat equivalents’. Each of the three sub-components is required to provide inflows to ‘food access’, which for comparison with energy requirements of the population will be expressed in kilocalories. This will require the inclusion of a unit conversion procedure in the flow from the sub-components to the Food Access component. Each sub-component is presented, using ‘cut-outs’ from the completed Food Access framework, presentation of which will conclude this section.

5.5.1 Income

Three sources of income predominate for subsistence farming households: agricultural income (sale of crops and livestock), remittances from men working away from home and casual employment of family members locally. The stocks and flows for these are represented in Figure 5.7 below.

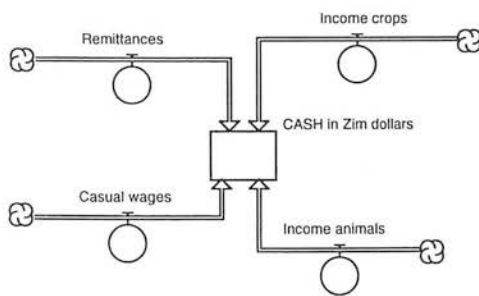


Figure 5.7 Stocks and flows for the income sub-component

Various influencing factors are then linked to each flow shown, to provide a framework for the detailed modelling calculations to be entered. Additional influencing factors can be entered by the modeller (or some of those in the framework removed). An indicative framework for income is shown in Figure 5.8 below.

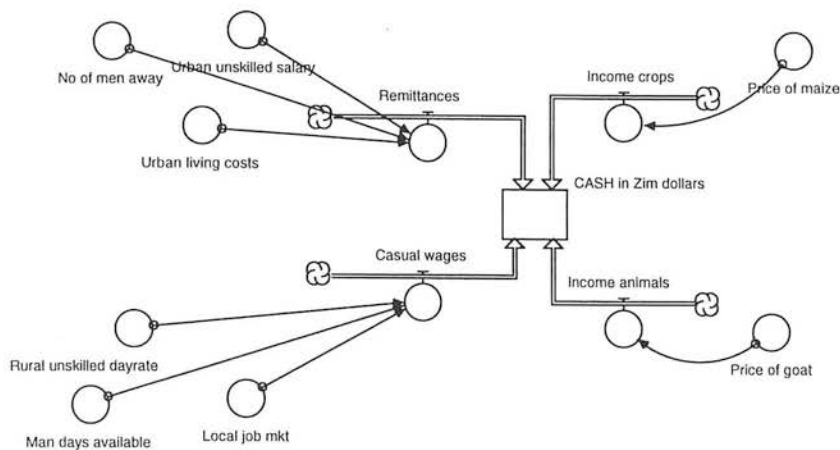


Figure 5.8 Income sub-component, including influencing factors

5.5.2 Expenditure

Household expenditure will comprise four elements: food purchases, agricultural inputs, livestock purchases and other goods and services (housing, clothing, school fees, health fees, consumer durables etc.). The stocks and flows for these are represented in Figure 5.9 below.

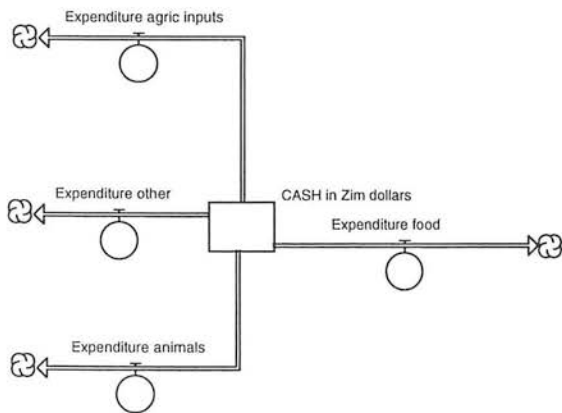


Figure 5.9 Stocks and flows for the expenditure sub-component

As with income, the various influencing factors are then linked to the flows to produce the framework for detailed modelling. An indicative framework is shown in Figure 5.10 below.

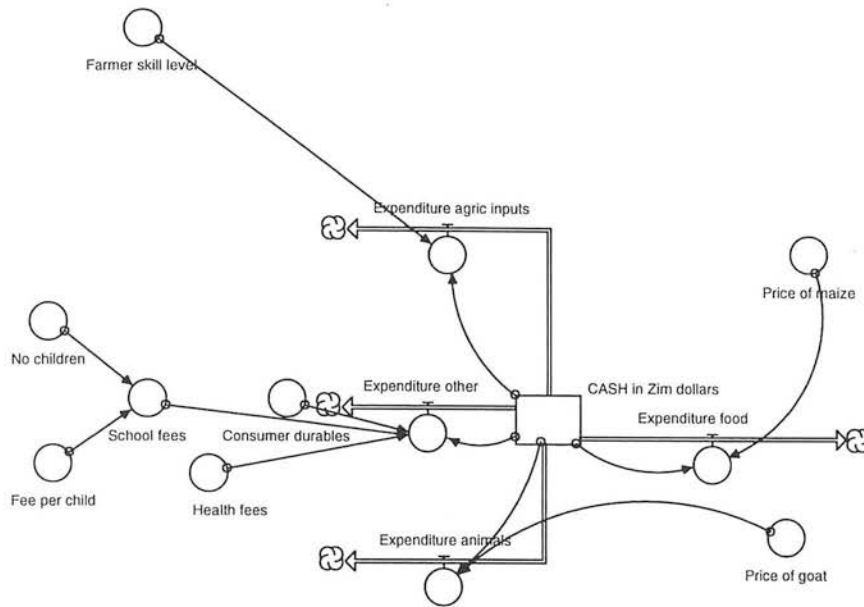


Figure 5.10 Expenditure sub-component, including influencing factors

5.5.3 Own production – arable crops

Within the sub-component ‘Own production / foraging’, the arable production and livestock keeping are treated separately. For arable crops the basic stocks and flows are as shown in Figure 5.11 below.

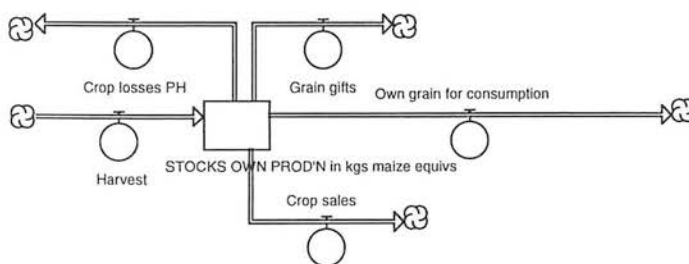


Figure 5.11 Stock and flows for the arable production sub-component

The above diagram shows that the only inflow to the stock relating to own production is the harvest flow. It should be noted that for simplification in this version of the framework, any other crops or food that have been purchased, received or foraged are regarded as food for immediate consumption and are input directly as flows to the food stocks. See the section 5.5.5, ‘Food for period,’ below. Stocks of own

production are assumed to suffer post harvest losses over time. They have three other outflows: for own consumption, for sale and for gifts to family members living away from the household.

The various influencing factors for own arable production are then linked to the stocks and flows, as shown in Figure 5.12 below.

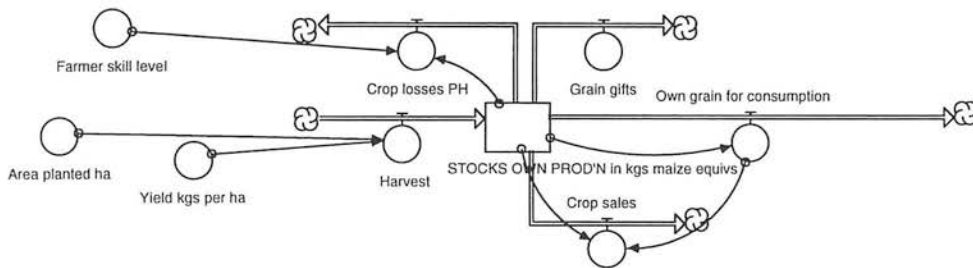


Figure 5.12 Arable production sub-component, including influencing factors

5.5.4 Own production – livestock

For livestock, the basic stocks and flows are as shown in Figure 5.13 below.

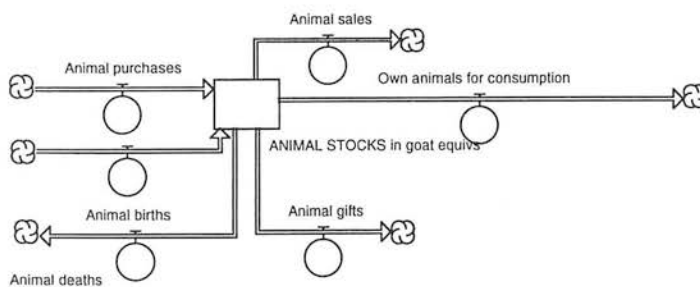


Figure 5.13 Stocks and flows for the livestock sub-component

For each class of animals (chickens, goats, cattle), births and deaths will change the numbers kept. In addition to births, the only other inflow assumed is from purchases. Apart from deaths, the other outflows are sales for cash, transfers for own consumption and gifts to family members away from the household. Adding the influencing factors to the stocks and flows gives the diagram in Figure 5.14 below.

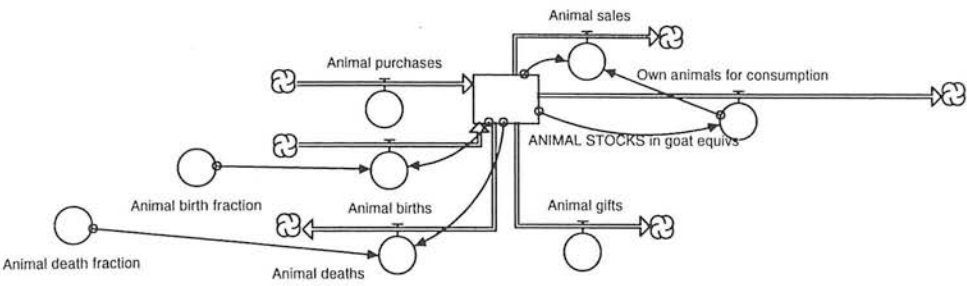


Figure 5.14 Livestock sub-component, including influencing factors

5.5.5 Food for period

In order to establish the level of food access for each time step, it is necessary to create a procedure to combine the food flowing from the various sources i.e. from cash expenditure, from consumption of own production or from consumption of own livestock, into a temporary stock, labelled ‘Food for Period’. This procedure is shown in Figure 5.15 below.

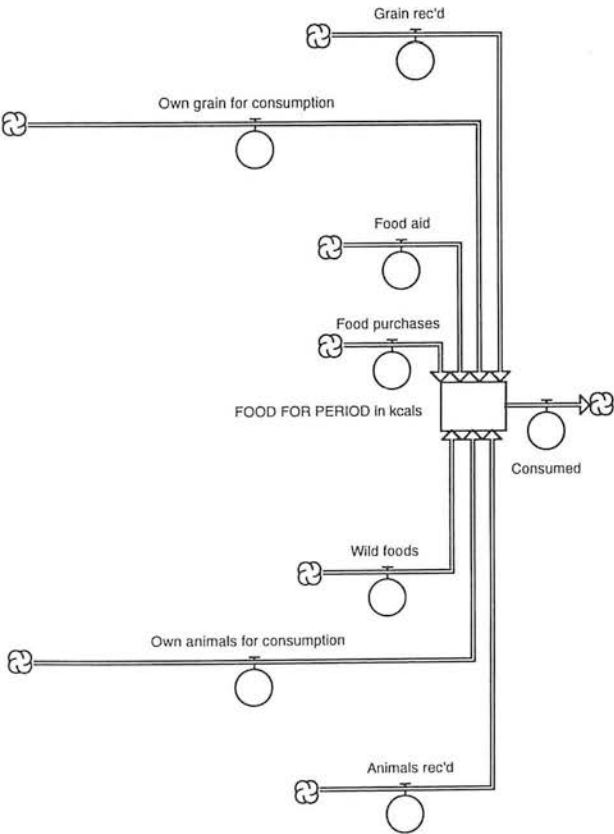


Figure 5.15 Stocks and flows for the ‘Food for Period’ procedure

In addition to the inflows of food from the three sub-components, the 'Food for Period' also takes into account gifts of grain and animals, wild foods and food aid. Three points should be noted about this procedure, for which the full diagram is shown in Figure 5.16 below. Firstly, as part of the accumulation of all inflows for the period, a unit conversion to kilocalories is carried out to by reference to the two conversion factors for maize and goats. This accumulation is a temporary stock of food 'Food for Period', which then flows out via 'Consumed' to an implementation of the 'four box' structure of the population cohorts. This is discussed in section 5.6, 'Health/Nutrition – Stage 1', below.

Secondly, this procedure includes an implementation of farmer decision making in relation to stocks and harvest expectations. Observed behaviour suggests that farmers sell part of their harvested crops immediately post-harvest, but retain stock as a precaution against a poor harvest in the following season. As the new season progresses, farmers have an increasingly accurate picture of harvest outturn. By mid-January or early February (in Zimbabwe), if the future prospects are good, farmers are able to sell the precautionary stocks set aside at the end of the previous season. Conversely, if prospects are bad, stocks will not be sold, but will be conserved for consumption i.e. they will assume a carryover stock to the next season will be required. If prospects are very bad, rationing of existing stocks and hence a reduction in consumption may be required. The modelling of these various harvest scenarios is facilitated by the inclusion of relevant influencing factors in the framework.

Thirdly, in a similar way to the implementation of future harvest expectations, the change in quality of the local ecosystem modulates the availability of wild food, which is usually a food of last resort for most families.

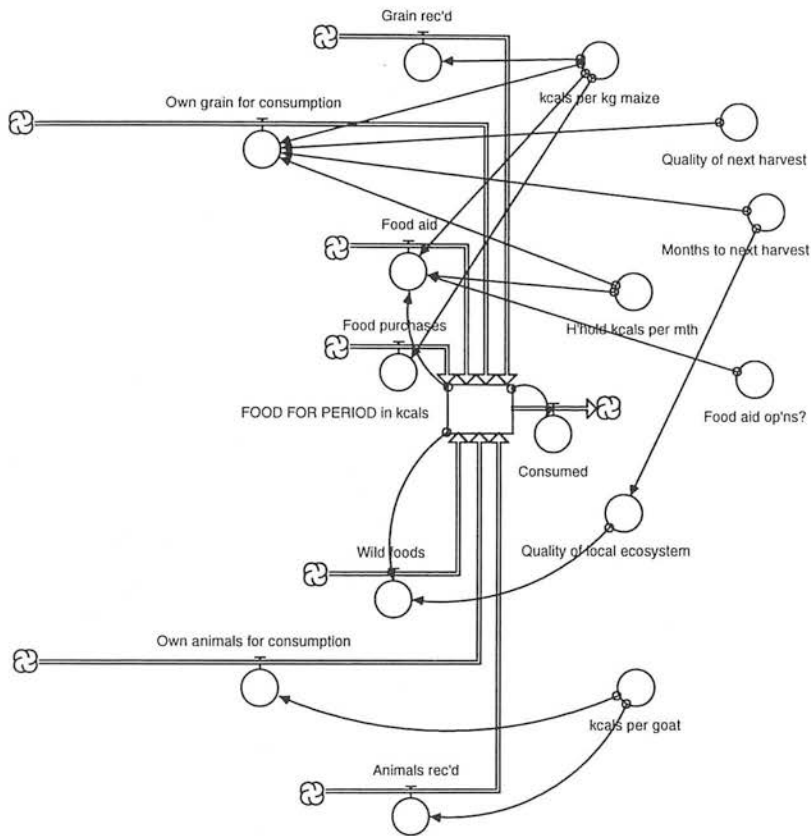


Figure 5.16 'Food for Period' procedure, including influencing factors

5.5.6 Food Access – the complete component

The sub-sections above have presented the three sub-components and the 'Food for Period' procedure that comprise 'Food Access'. The 'cut-outs' used therein were taken from the full diagram of the modelling framework for 'Food Access'. The stocks and flows version of this is shown in Figure 5.17 below.

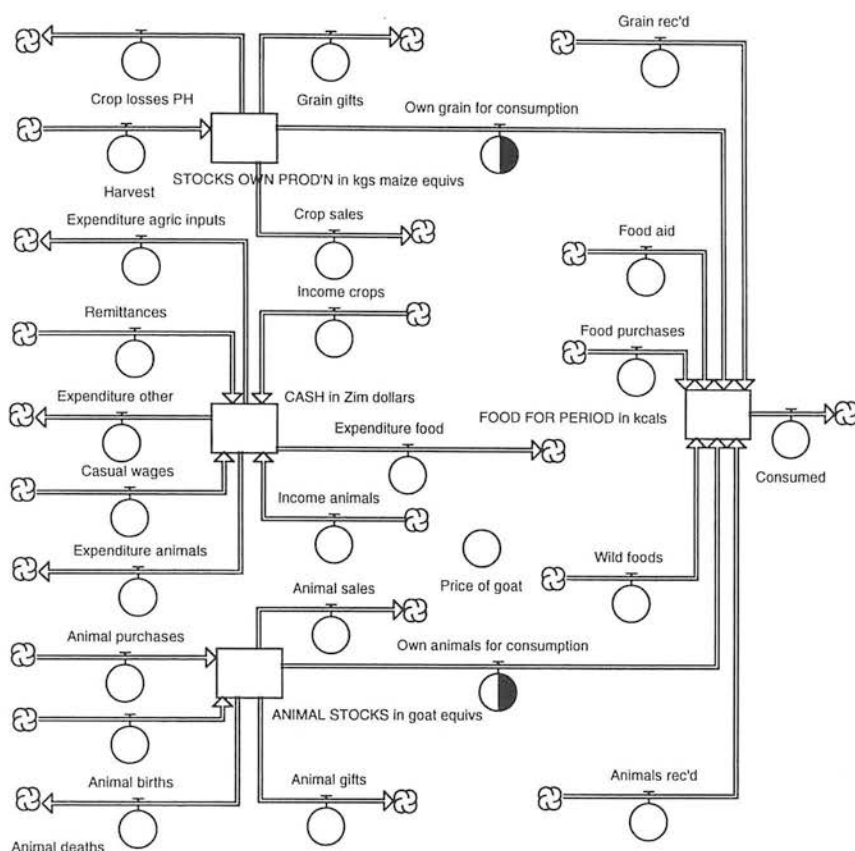


Figure 5.17 Stocks and flows for the 'Food Access' component

As noted in the previous sub-section, the more productive farmers sell crops immediately post-harvest and again, if prospects are good, midway through the next season. In bad seasons, they may be purchasers of grain later in the season. Poorer households are net buyers of grain in most years and make purchases throughout the season. Included within this first prototype of the modelling framework for 'Food Access' is a simple price mechanism for converting crop sales (in the own production sub-component) into a cash inflow (in the income sub-component). Similarly, cash spent on food (in the expenditure sub-component) is converted to food purchases in the 'Food for Period' procedure. (Animal sales and purchases are similarly implemented.). The full diagram of the 'Food Access' component, including all influencing factors, is shown in Figure 5.18 overleaf.

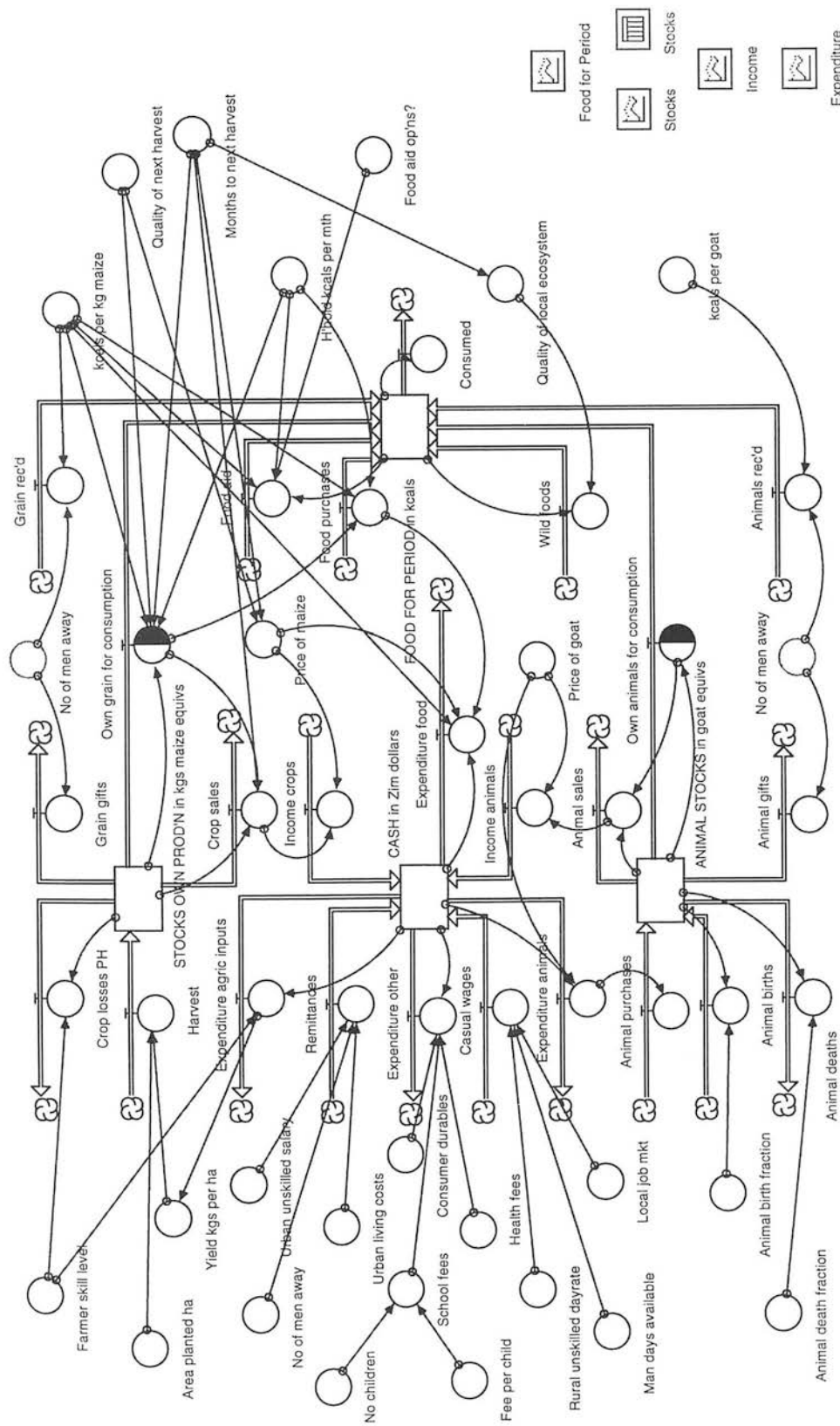


Figure 5.18 'Food Access' component

(N.B. In Figure 5.18 the half-shaded flows ‘Own grain for consumption’ and ‘Own animals for consumption’ indicate that unit conversion to kilocalories is automatic.)

As noted previously, there is a coding layer beneath the graphical user interface that is used to detail the relationships between the stocks, flows and influencing factors. The coding for the Food Access component, which has been implemented as a simplified working model, is given in Appendix V. The simulation runs for one year, in time steps of one month. ‘Screenshots’ are reproduced below:

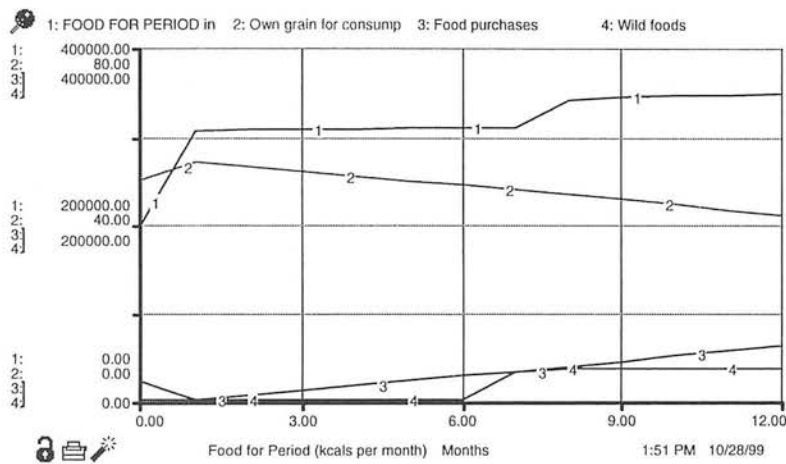


Figure 5.19 Food for each period and main sources thereof

(N.B. the ‘Own grain for consumption’ is scaled as kilograms of maize and is therefore comparable with the kilocalories scale of the other variables)

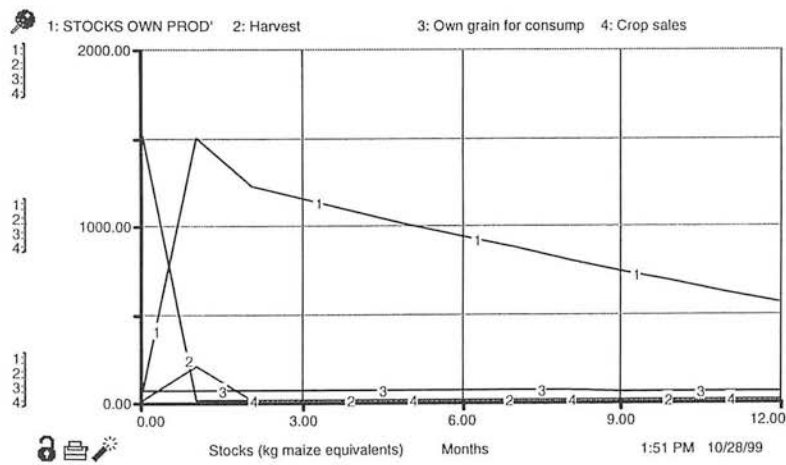


Figure 5.20 Stocks, harvest, own grain consumption and crop sales for each period

1:26 PM 11/3/99 Stocks (kg of maize equivalents)

Months	STOCKS OW	Harvest	Own grain for	Crop sales		
0	50.00	1,500.00	50.00	0.00		
1	1,489.50	0.00	54.00	193.50		
2	1,217.11	0.00	52.92	0.00		
3	1,142.02	0.00	51.91	0.00		
4	1,068.69	0.00	50.89	0.00		
5	997.11	0.00	49.86	0.00		
6	927.28	0.00	48.80	0.00		
7	859.21	0.00	47.73	0.00		
8	792.88	0.00	46.64	0.00		
9	728.31	0.00	45.52	0.00		
10	665.51	0.00	44.37	0.00		
11	604.49	0.00	43.18	0.00		
Final	545.26					

Figure 5.21 Stocks, harvest, own grain consumption and crop sales for each period

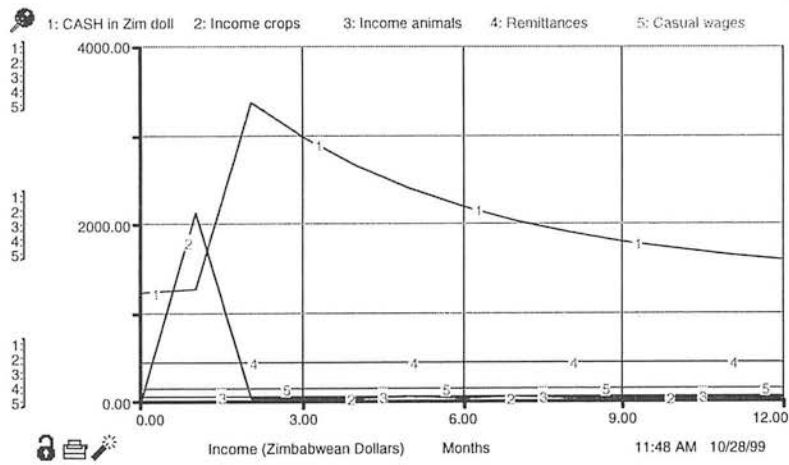


Figure 5.22 Cash and income sources

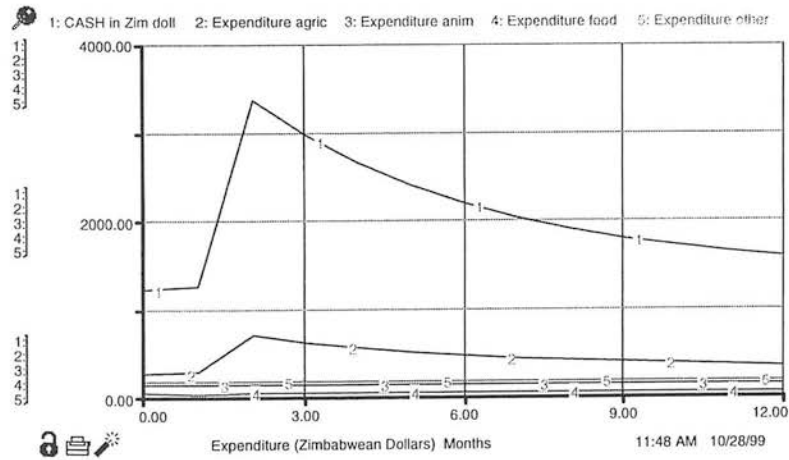


Figure 5.23 Cash and expenditure

Although the above figures are taken from a simplified working model of the Food Access component, it will be helpful to provide a commentary of the scenario depicted therein. The household modelled is assumed to comprise two adults and two children, with an additional adult male working away and remitting funds regularly. The monthly nutritional requirements are assumed to be 300,000 kilocalories, of which 90% will come from staples, produced on the farm. The harvest occurs in month 0 and any surplus grain, over and above that required to meet the current and next season's requirements will be sold in month 1, with payment received in month 2 (as per G.M.B. payment procedures). Shortfalls in staples from own stocks are met by purchases and wildfoods, the latter becoming available after month 6 of the season. For the year modelled, the harvest is good (1,500 kg of maize for 1 ha planted). As a result the household maintains monthly consumption above nutritional requirements and both stocks and cash are at higher levels at the end of the year than at the outset.

The component above appears to behave reasonably, as implemented for a single household. It can thus be considered to meet Oakshott's first stage 'Face validity'. The second and third validation stages could only be carried out when the individual sub-components were implemented by colleagues on the collaborative project.

However, some critical comments are required about the Food Access component and its ability to represent the spatial variabilities in household characteristics identified in the analysis of the household survey. There are two aspects to this. Firstly, there is a need to reflect the different values associated with households in different locations in the initial stock conditions and the influencing factors – the spatial dependencies. Secondly, there is a need to reflect the differences between households located within the same location – the heterogeneities.

The findings reported in chapter 2 show significant spatial dependency between household characteristics for agro-ecological zones in the study district. In particular, those relating to agriculture and household income, expenditure (see Tables 3.7 and 3.8), which form the principal sub-components of 'Food Access'. The spatial dependencies could be incorporated by using multiple instantiations of the Food Access component, with one representative household for each location. For example, assuming the Buhera District was being implemented and there were known

to be zonal and ward level dependencies, it would be necessary to instantiate 30 household models, i.e. one per ward. These would need to be simulated in parallel to ensure that inter-ward grain transactions, via traders, could be correctly modelled.

The heterogeneities within locations are reflected in the distributions of the values attributed to initial stocks and to influencing factors. It may seem straightforward to incorporate this variability by simply substituting single valued variables with stochastic variables drawn from probability distribution functions, a standard feature of systems dynamic modelling software. However, as very few of the household characteristics are independent, correlation will exist between them and the use of individual probability distribution functions for each variable, in isolation, would not be valid.

It would be feasible to create a covariance matrix for all characteristics, for each ward, but this would need to be dynamically accessed each time that a variable was called within the simulation, for each of the multiple household instantiations required for the spatial dependencies. To do this would have required substantial modification to the systems dynamic software, which was not felt to be appropriate at this point in the work. The alternative solution, not requiring such software modifications, would have been to instantiate multiple models not only for the spatial dependencies, but also for the heterogeneities of households within each location. This would clearly be a large number of models and the feasibility of this approach is discussed in the 'Remarks' section of this chapter.

5.6 Health/Nutrition – stage 1

In this first system dynamic version of the modelling framework, health is incorporated within the nutrition component, based around the 'four-box' concept outlined above. The 'Food for Period' from the Food Access component is passed to the Health/Nutrition component and the sufficiency or otherwise of kilocalories available to the children and adults, determines their nutritional status by re-categorising the individuals at each time period in the simulation. The stocks and flows designed for this approach are shown in Figure 5.24 below.

This diagram shows the ‘Food for Period’ transferred from the Food Access component and allocated to the two population cohorts, children and adults. The basis of the allocation between cohorts can be either the relative kilocalorie requirements of each cohort or a weighting / rationing scheme. From this point, the two cohorts are split into the four categories: healthy, malnourished, sick and sick-and-malnourished and flows between the categories occur as a result of the food allocations and the level of infection and quality of care available to each cohort / category.

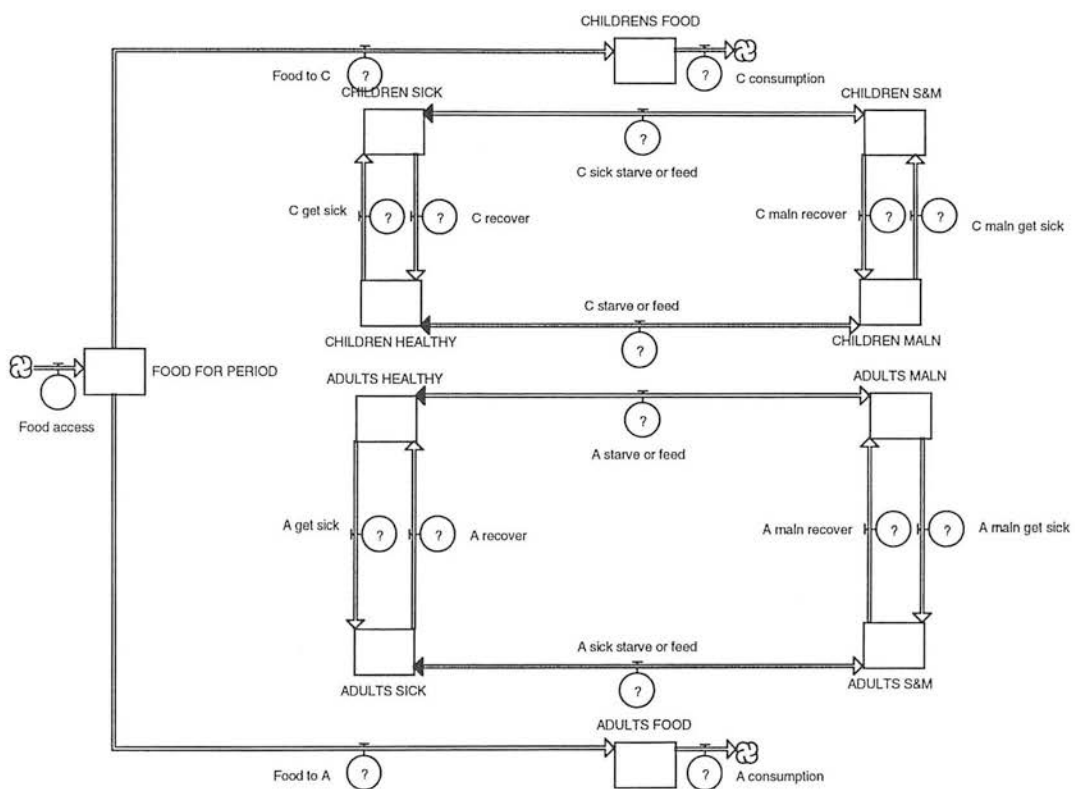


Figure 5.24 Stocks and flows for the ‘Health/Nutrition’ component

Once allocated to the two cohorts, food is then passed (pro-rata to requirements) to each of the four categories within each cohort: healthy, malnourished, sick and sick-and-malnourished within each cohort. By comparison of allocation and requirement, individuals within each category may remain in their current nutritional state or be transferred to another category. This is carried out by the influences shown in Figure 5.25 below which linked the nutritional bi-flows (the upper and lower horizontal flows in each four-box set, labelled ‘StarveFeed’) to the numbers in each category and the food allocated. Table 5.1 below illustrates the outcomes for this process:

From:	To (if food sufficient):	To (if food insufficient):
Healthy	Healthy	Malnourished
Malnourished	Healthy	Malnourished
Sick	Sick	Sick-and-malnourished
Sick-and-malnourished	Sick	Sick-and-malnourished

Table 5.1 Outcomes for food sufficiency, by category

In a similar way, the level of infection and quality of care available to each cohort / category influence the change in category, shown by the two vertical ‘uniflows’ on left and right side of Figure 5.24, labelled ‘Infect’ and ‘Recover’. The outcomes for the different levels of infection and care are shown in Table 5.2 below:

From:	To (if infected):	To (if recover):
Healthy	Sick	N/A
Malnourished	Sick-and-malnourished	N/A
Sick	N/A	Healthy
Sick-and-malnourished	N/A	Malnourished

Table 5.2 Outcomes for infection and recovery, by category

Rates of infection and recovery, for each category of each cohort are included as influencing factors in the full Health/Nutrition component, shown in Figure 5.25 below:

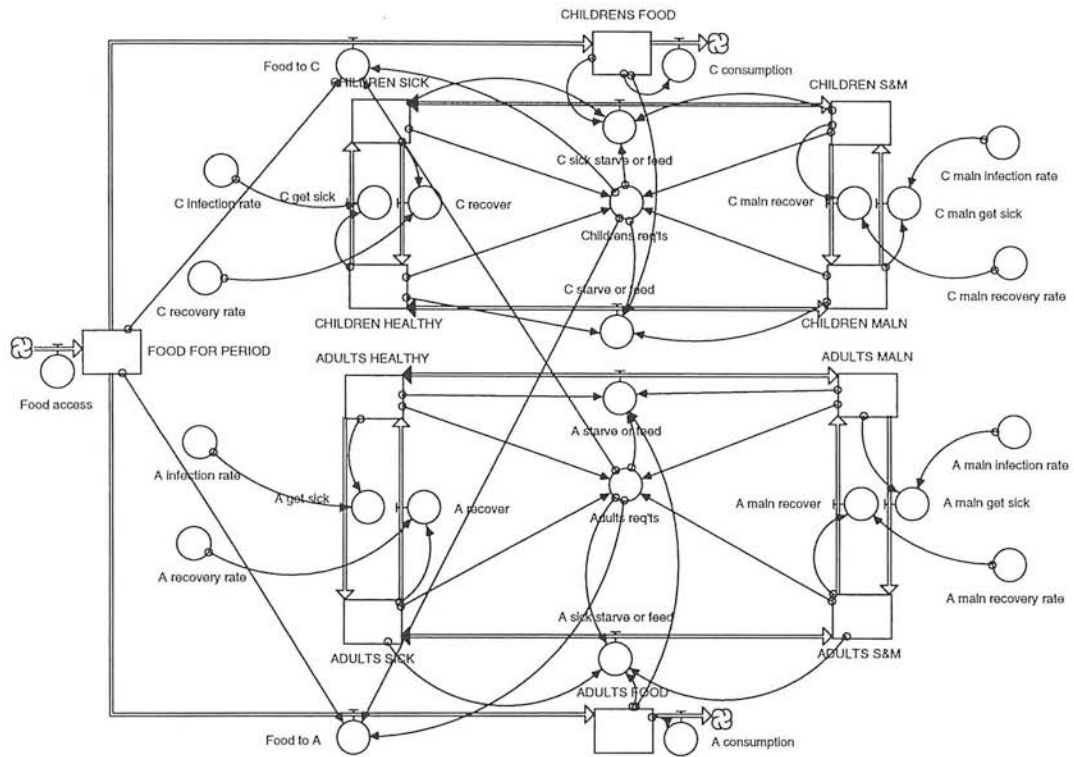


Figure 5.25 'Health/Nutrition' component

In this first version of the 'Health/Nutrition' component, the modelling framework retains the simplification of a steady state population, omitting births, deaths and ageing (i.e. transferring from children to adults). In later versions of the systems dynamic frameworks, births and deaths are included, but ageing remained unimplemented.

As with 'Food Access', the 'Health/Nutrition' component of the framework shown above was implemented as a simplified working model and the coding for this is shown in Appendix VI. The simulation also runs for one year in monthly time steps. However, although the 'Food Access' component was implemented as a single household model, the 'Health/Nutrition' component represents a community of 2,000 individuals (500 adults and 1,500 children). This difference of scale was deliberate. The rationale was that the majority of the health influencing factors operated above household scale (e.g. infection rates, access to clinics) and that the application of sickness and recovery rates drawn from these would be more appropriately applied to

a community, rather than separate households. The implications of this for the overall framework design are discussed in the remarks section below.

The various graphs and tables were produced from this working model and the ‘screenshots’ of these are shown below.

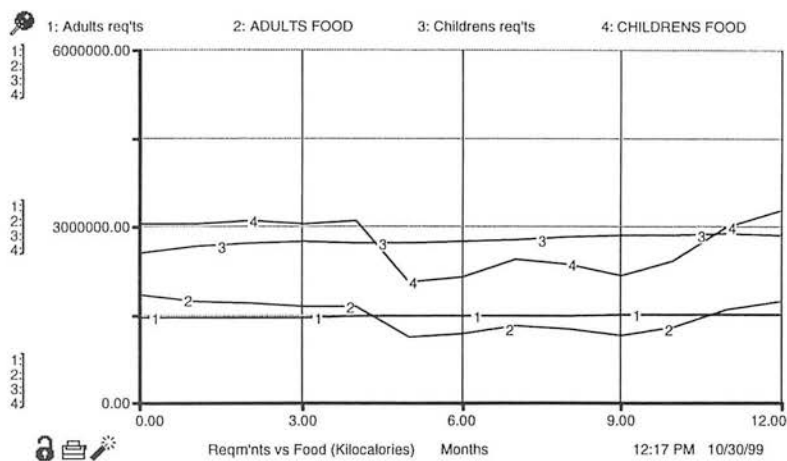


Figure 5.26 Food availability and cohort requirements

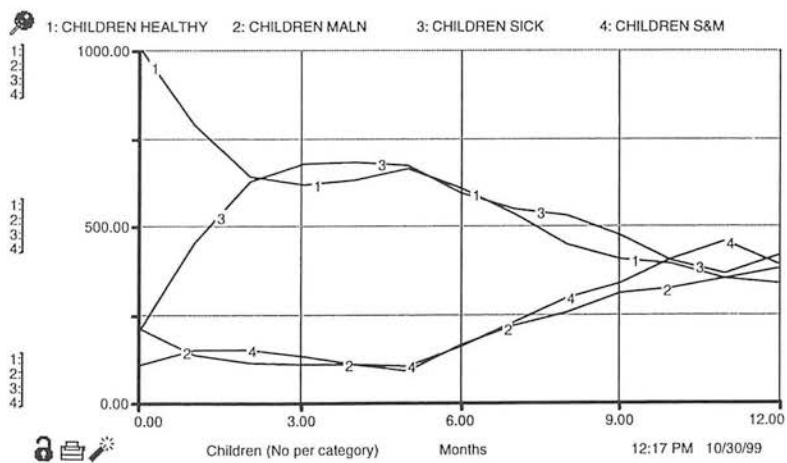


Figure 5.27 Children's health and nutritional categories

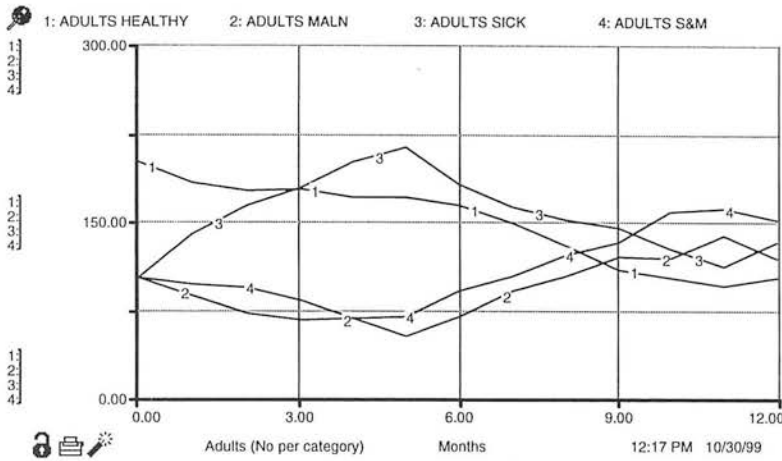


Figure 5.28 Adults' health and nutritional categories

A brief commentary on this simplified working model follows. The graphs in Figures 5.26 to 5.28 illustrate the effect of using a set of simplistic assumptions of food availability and rates for malnutrition and infection. The model has a built in lag between supply and consumption reflecting household short term storage of food, of approximately two months' supply. Food is supplied through a dummy 'Food Access' flow, which is a random variable, drawn from a uniform distribution, as represented by the 'cloud' icon on the left of figure 5.25. The level of food supplied has a mean of 250 kilocalories per capita per day above nutritional requirements for the first and fourth quarter of the year and 250 kilocalories per capita per day below requirements for the second and third quarters. This represents the scenario of good food supply immediately post-harvest, followed by a six month 'lean' period (during the Zimbabwean winter), followed by an improvement in food supply in the early summer as 'green' maize and wildfoods supplement the diminishing stored crops. As food is above requirements until month five (Figure 5.26) the number of children and adults in malnourished categories initially fall, but rise quite sharply from month five onwards, only to fall again at the end of the year (Figures 5.27 and 5.28).

Very simple mechanisms have been coded to implement the four flows of 'Starve' / 'Feed' and 'Get Sick' / 'Recover'. These are as follows:

'Starve' / 'Feed' – where the food allocated to a 'Healthy' or 'Sick' category within either of the two cohorts cohort is less than nutritional requirements for that category,

transfer a proportion (arbitrarily set at 0.1) of the individuals to the ‘Malnourished’ or ‘Sick-and-Malnourished’ category. If food allocated exceeds requirements transfer a proportion (arbitrarily set at 0.1) of the individuals, in the other direction, i.e. from ‘Malnourished’ or ‘Sick-and-Malnourished’ to the ‘Healthy’ or ‘Sick’ category.

‘Get Sick’ / ‘Recover’ – arbitrary infection and recovery rates are included and are random variables, drawn from a uniform distribution, with means as follows:

	Infection rates		Recovery rates	
	Summer	Winter	Summer	Winter
	(Q1&Q4)	(Q2&Q3)	(Q1&Q4)	(Q2&Q3)
Children, Healthy	0.25	0.35	0.2	0.3
Children, Malnourished	0.35	0.45	0.3	0.4
Adults, Healthy	0.15	0.25	0.1	0.2
Adults, Malnourished	0.25	0.35	0.2	0.3

Table 5.3 Infection and recovery rates for children and adults

Note that the ‘Get sick’/‘Recover’ flows control the movement of children and adults from the two non-sick states (‘CHILDREN HEALTHY’, CHILDREN MALN’ etc) to the two sick states (‘CHILDREN SICK’, CHILDREN S&M’ etc) and not between the nutritional states. Flows between nutritional states are described in the paragraph above relating to ‘Starve’/‘Feed’. Thus, by definition there are only two types of flow for sickness states and for nutritional states. For any given flow, from any given cohort/category, the proportion shown by the table above is transferred between categories in accordance with Table 5.3.

The initial composition of the population is as follows:

	Children	Adults
Healthy	1,000	200
Malnourished	200	100
Sick	200	100
Sick-and-malnourished	100	100
Total	1,500	500

Table 5.4 Initial health/nutritional composition of population

In parallel with the malnutrition mechanisms, the sickness and recovery rates have the effect of reducing the number in each of the two cohorts' healthy categories, with a corresponding rise in numbers in the sick categories. After food availability is reduced, individuals in the healthy/sick categories begin to be transferred to the malnourished/sick-and-malnourished categories, until month eleven, when the position reverses.

One obvious criticism of this 'Health/Nutrition' component of the framework is the over-simplification of infection and care to be represented by the single influencing factors 'Get Sick' and 'Recover'. There is a need to allow modellers to reflect a range of diseases within this component and also to allow spatial variability of the disease and recovery mechanisms. This was addressed in the second version of this component, described in the section 'Health/Nutrition – stage 2', below.

5.7 Implemented models

The two components of the modelling framework described above formed the basis of several models implemented by colleagues within the collaborative research project. It will be observed that the Food Access component of the framework effectively allows the modelling of one household, whereas the Health/Nutrition component is concerned with a community. This difference of scope was recognised as a potential problem. However, for the various implementations carried out at this stage of the collaborative research project, the Food Access component was implemented as a single household and the 'Food for Period' scaled up by the number of households in

the community. One such implementation, which investigated the effects of maize pricing by the Zimbabwean parastatal Grain Marketing Board (G.M.B.) is shown in the diagram in Figure 5.29 overleaf.

Although the purpose of this thesis is to present the design of the modelling framework, rather than describe the models implemented by others using the framework, some brief comments about the model in Figure 5.29 will be made.

Firstly, the own production/foraging sub-component of 'Food Access' has been restricted to a single food grain, maize. Secondly, livestock keeping has been treated as an asset-owning function, rather than an agricultural enterprise. As a result, livestock have been subsumed within a more general asset class and income and expenditure arising therefrom are simple sales and purchases of the assets themselves, rather than products or services derived from the livestock. Thirdly, in the 'Health/Nutrition' component, additional influencing factors have been appended to incorporate births, deaths and growth of children into adults.

The various simplified models presented above, together with the limited implementations by colleagues, demonstrated that the 'Food Access' and 'Health/Nutrition' components of the framework were 'producing reasonable results' and as such satisfied the test of 'Face validity', the first stage of Oakshott's approach to simulation validation referred to in section 5.3 above.

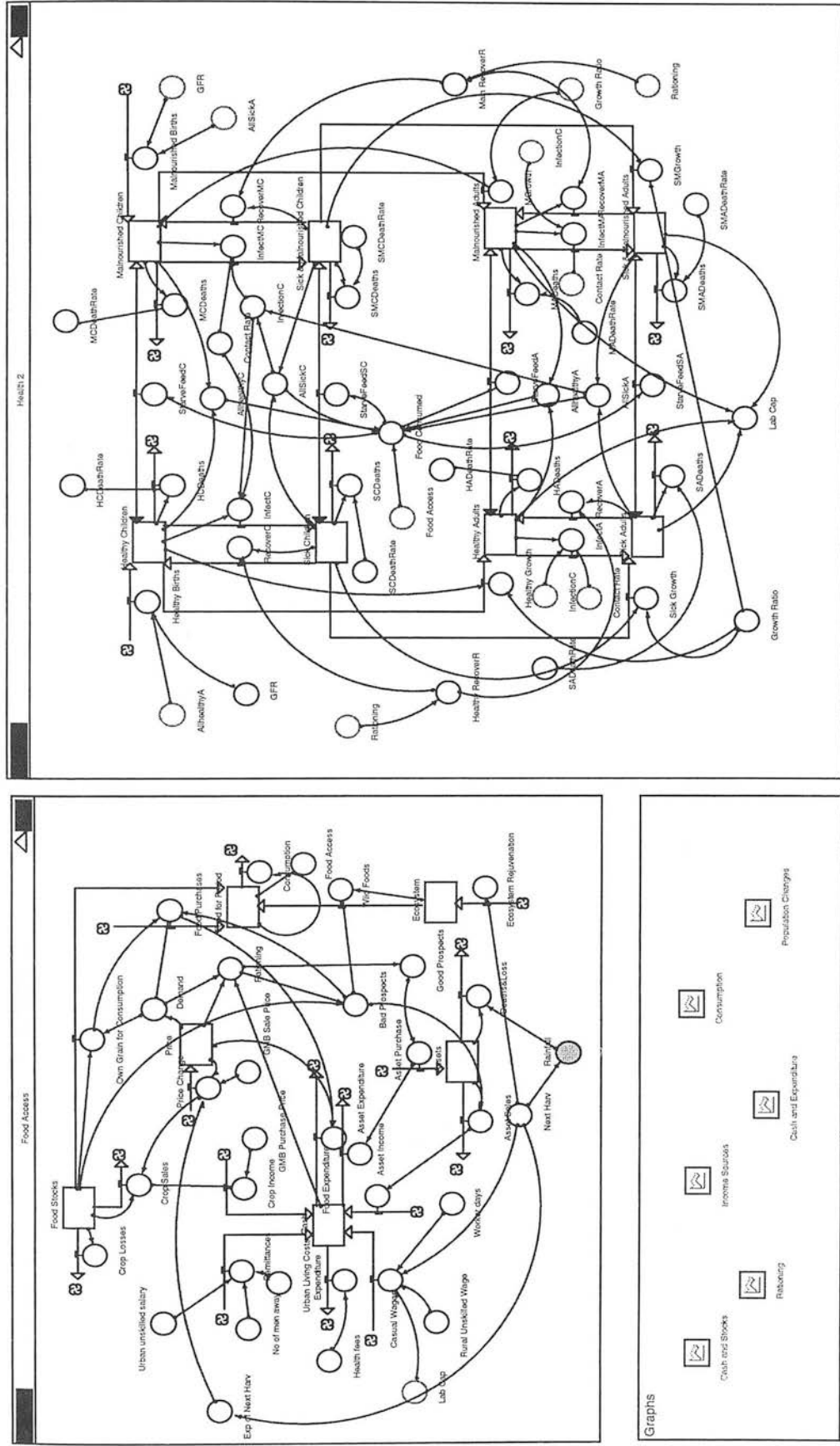


Figure 5.29 Example of a model implemented using the systems dynamic framework

5.8 Health/Nutrition – stage 2

As noted, the ‘Health/Nutrition’ component required improvement to allow a range of diseases and to incorporate spatial variability of the disease and recovery mechanisms. Also, the inclusion of births and deaths had been carried out on an *ad hoc* basis within implemented models of ‘Health/Nutrition’ and there was a need to incorporate such procedures within the framework. Malnutrition mechanisms, relying on a simple assessment of food available being ‘greater or less than’ requirements were too coarse and needed enhancement.

The ‘Health/Nutrition’ component of the framework was therefore revised. Although the underlying flow structure of the earlier version was retained, the revised version includes six sub-components:

- Food Consumption
- Children
- Adults
- Morbidity and mortality (children)
- Morbidity and mortality (adults)
- Long term locational factors

5.8.1 Food Consumption

The revisions to the food consumption procedures were designed to provide an influencing factor to the malnutrition mechanisms of ‘Needs satisfied’, for children and adults. This ‘Needs satisfied’ factor was calculated as the food allocated to each of the two cohorts, expressed as a percentage of the dynamic kilocalorie requirements (i.e. as recalculated at each time period to allow for changing requirements brought about by births, deaths and changes in illness and malnourishment status).

The diagram for this sub-component is shown in Figure 5.30 below.

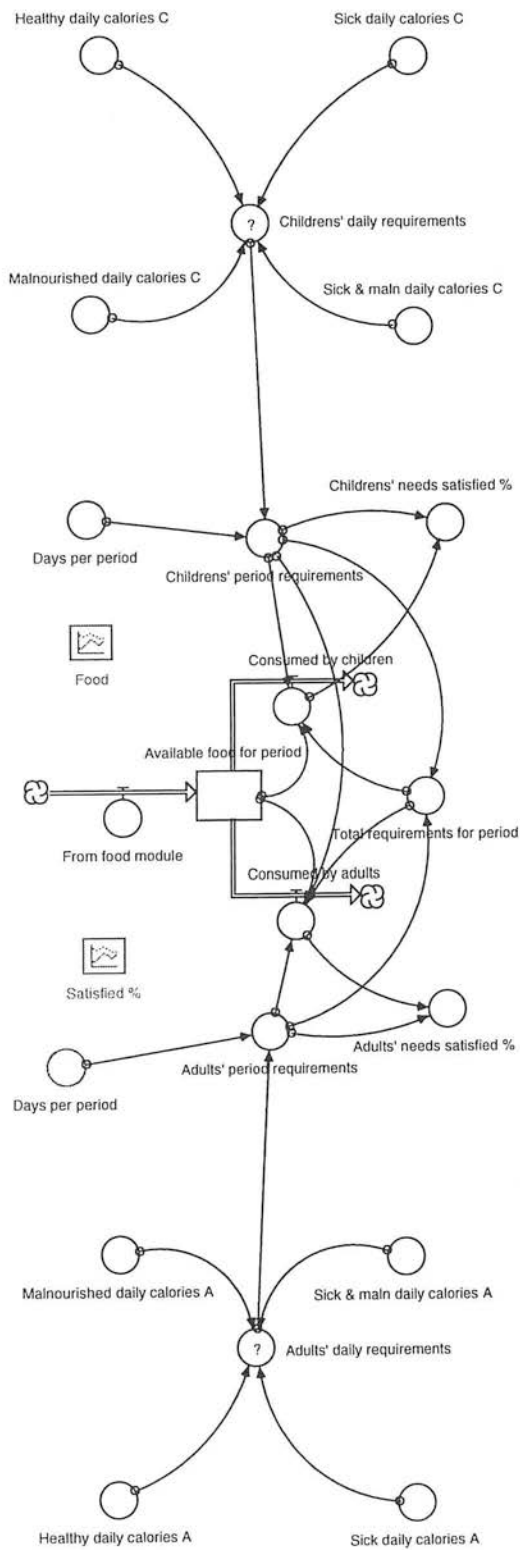


Figure 5.30 'Food Consumption' sub-component

5.8.2 Children

To the categories of original ‘four-box’ structure of healthy, malnourished, sick and sick-and-malnourished, two additional stocks were added to accumulate the deaths due to hunger and to illness. As well as providing a more realistic framework, these accumulations facilitate the reporting of mortality from the implemented models. In addition, birth flows are added and rather than having arbitrary health/nutrition status (e.g. all births assumed healthy), the births are allocated to the same health/nutrition category as the mother. This is carried out by linking the birth flows to the adult health/nutrition categories and to the birth rate factor. The flows between healthy / malnourished and sick / sick-and-malnourished are linked to the ‘Children’s needs satisfied %’ referred to above. The diagram for children is shown in Figure 5.31 below.

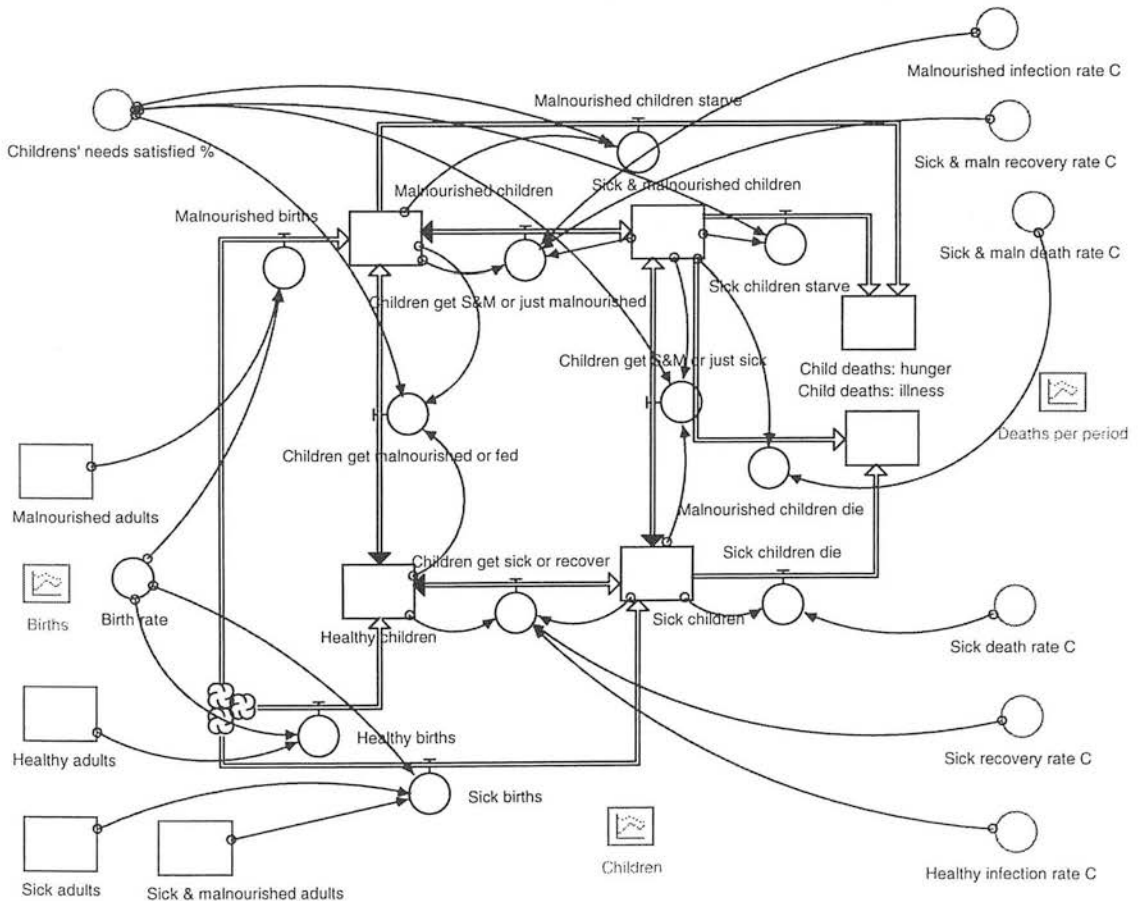


Figure 5.31 ‘Children’ sub-component

5.8.3 Adults

Adult deaths are incorporated in this sub-component by the same method as children's deaths. Although obviously no births of adults occur, an additional flow is included to reflect the migration or return of men working away and so adjust the nutritional needs of the community to more closely reflect the numbers resident at any given time period. This migration flow is assumed to be to/from the 'Healthy' category as migrants are unlikely to leave for the urban areas if ill (as they will not be given work) and unlikely to return sick (as general living conditions in urban areas, are better from a nutritional and health standpoint).

(The AIDS/HIV infection rate presents more general problems for modelling the interaction between food access and health, as morbidity and mortality data are not reliable for this illness. See for example Daley et al (1998) 'Surveillance is practically and logistically difficult in many parts of the continent, resulting in significant underreporting.' However, the United Nations 1998 Revision of World Population Estimates and Projections (United Nations, 1998) states that in Zimbabwe 'one in every five adults is infected' and this could perhaps be used as the background rate in any model implemented for Zimbabwe.)

The diagram for adults is shown in Figure 5.32 below.

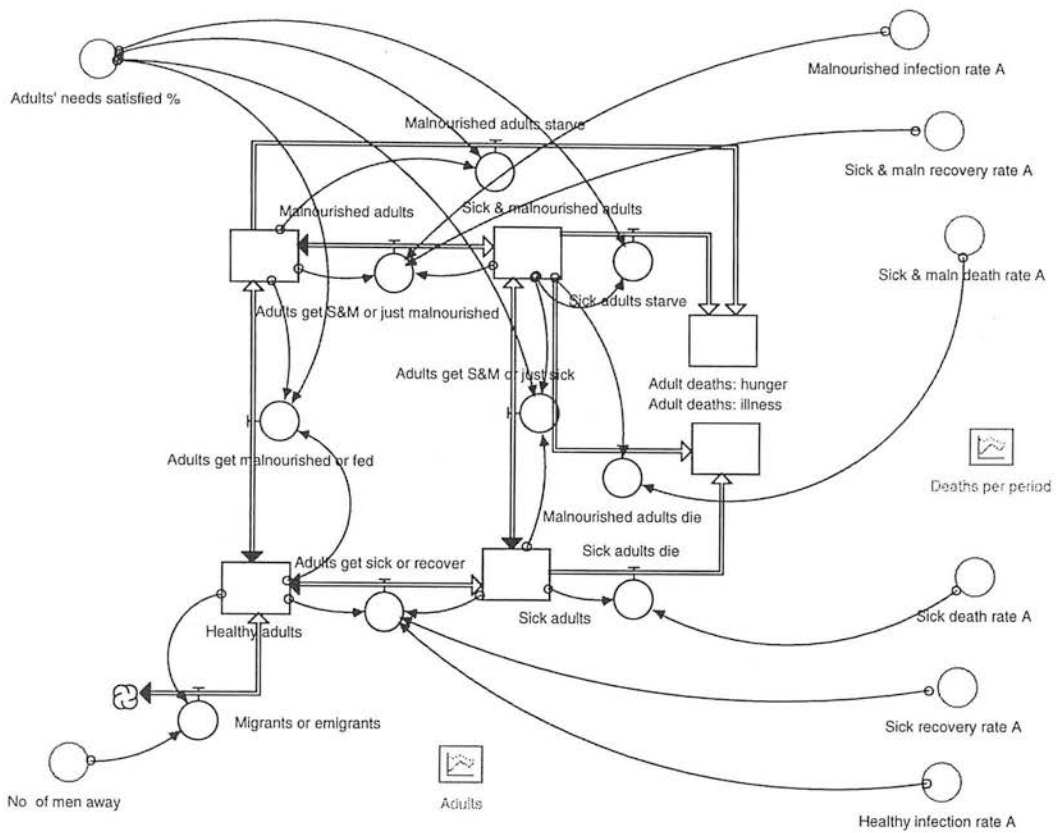


Figure 5.32 'Adults' sub-component

5.8.4 Morbidity and mortality (children)

For modelling spatial variability of disease in Zimbabwe, monthly morbidity and mortality data are available, through the health clinic reporting system of 'T5' forms. Robust data are available at an aggregation level of district (see section 4.8.2). These data can be used to provide a monthly 'background' rate for the main disease categories, which can be modulated by locational influencing factors drawn from other secondary data. The locational influencing factors can also be used to modulate the recovery rates used.

By using the five illness groups that are reported separately on the 'T5' forms (diarrhoea, measles, respiratory infection, malaria and HIV/Aids), the 'T5' statistics can be input to the implemented models as tabular data, as shown in the 'Children - morbidity and mortality' sub-component shown in Figure 5.33 below.

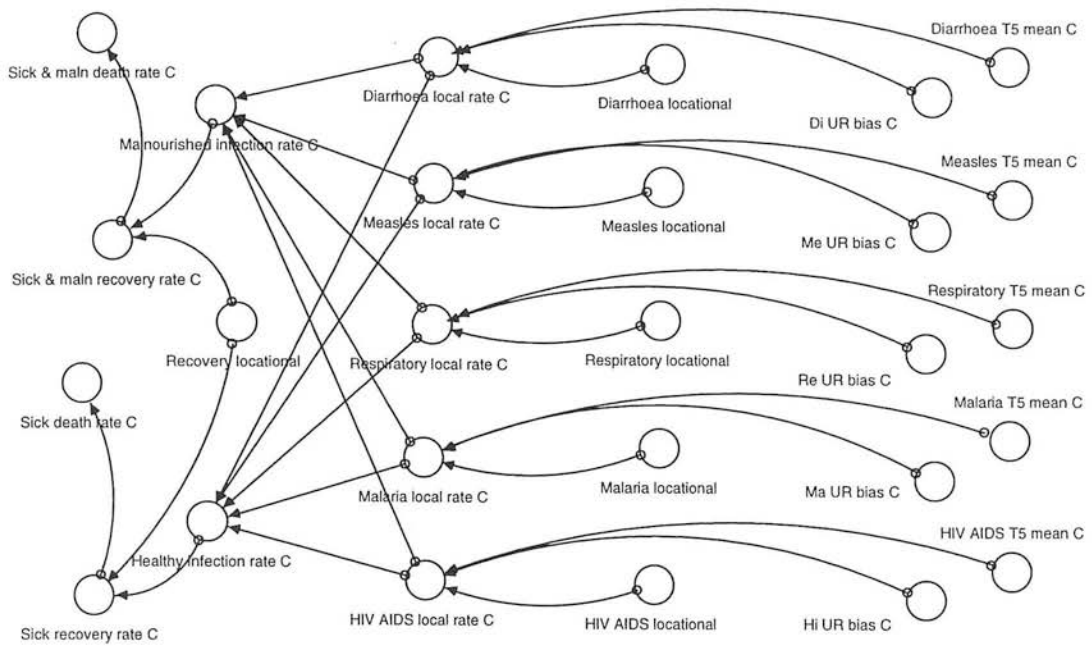


Figure 5.33 ‘Morbidity and mortality (Children)’ sub-component

Note that the ‘T5’ data for each illness group can be adjusted to reflect the under reporting bias in the health clinic statistics (see Wright (1998) for details of this bias in health statistics reporting in Zimbabwe). Combining these data with the locational factor for each illness group (calculated as described below), allows a local infection rate for each illness group to be calculated. These rates are then aggregated to provide two infection rates applicable to children in the ‘Healthy’ and ‘Malnourished’ categories (the latter being set relative to the ‘Healthy’ rate, based on expert local knowledge). Again by combining locational factors with expert local knowledge, the mortality and recovery rates can be imputed from the infection rate.

5.8.5 Morbidity and mortality (adults)

The sub-component for adult morbidity and mortality is functionally identical to that described above for children.

5.8.6 Long term locational factors

For the illness groups used in the morbidity and mortality sub-components described above, the monthly ‘T5’ data are aggregated at district level and mask spatial

variability within the district. The ‘Health/Nutrition’ component simulates community level nutritional security and thus ideally morbidity and mortality data for ward or sub-ward are required. These can be obtained by modulating the district level data with ward (or sub-ward) locational factors known to influence each illness group rate. Locational factors can also be applied to the imputed recovery rates for all groups, based on care factors such as ward level access to clinics, religion and customs etc. An example set of locational factors is shown in Figure 5.34 below.

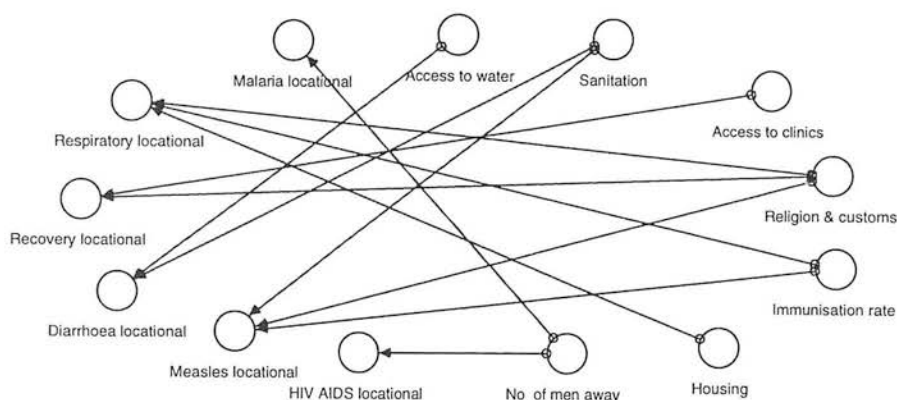


Figure 5.34 ‘Long term locational factors’ sub-component.

In order to demonstrate the revised version of the ‘Health/Nutrition’ component, a working model was implemented by the author, using arbitrarily chosen data and simplified assumptions for some of the encoded relationships. The diagram for the whole component, essentially a combination of all sub-components shown above, plus adult morbidity and mortality, is shown in Figure 5.35 overleaf. Coding for this working model is enclosed in Appendix VII.

Graphical and tabular outputs for the revised component are similar to those charts and tables presented earlier in this chapter. Additional charts have been implemented to report the extent to which cohort nutritional requirements are satisfied; births by number and health/nutrition category; infection rates and deaths. Example of these, from the working model, are shown in Figures 5.36, 5.37, 5.38 and 5.39.

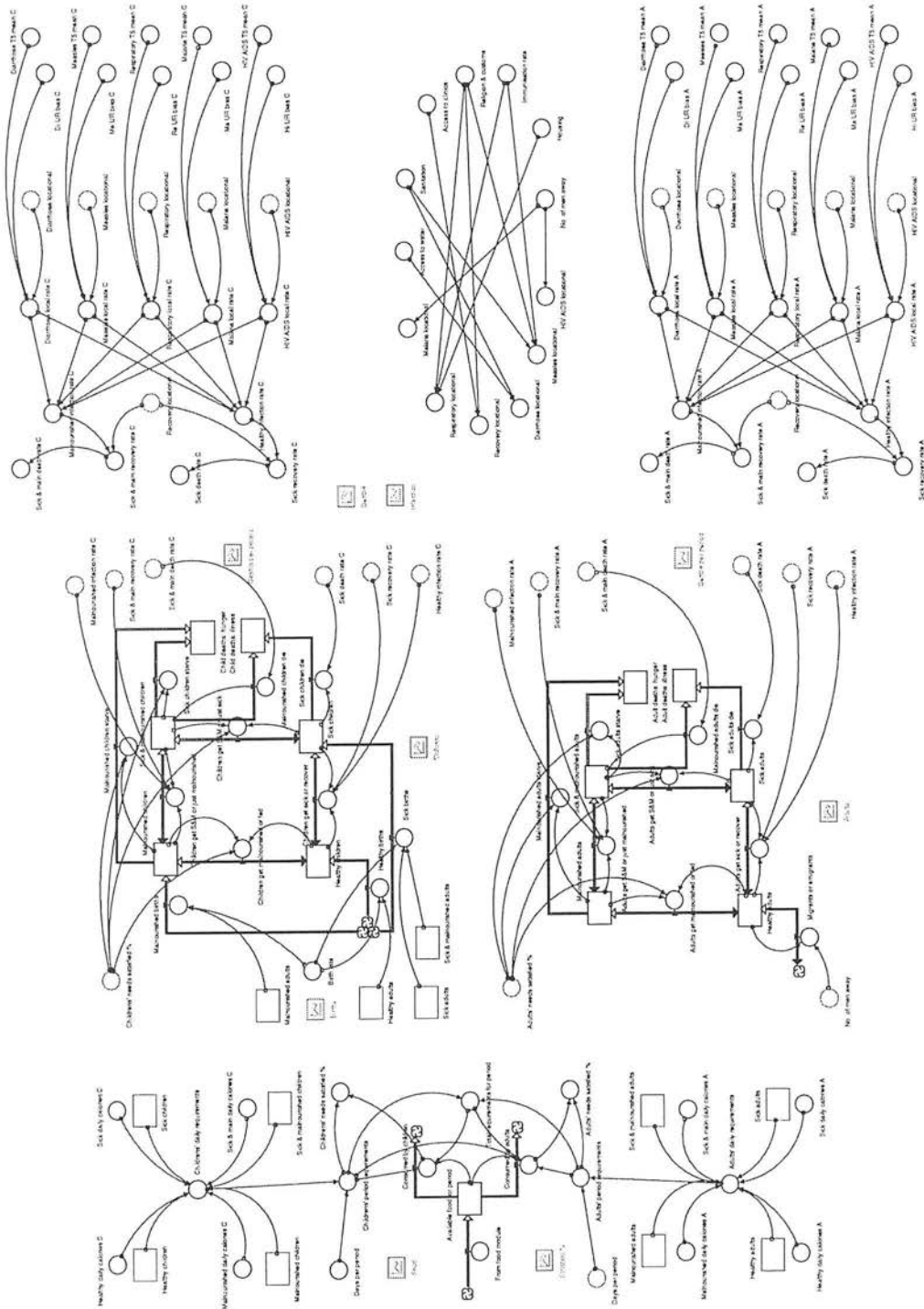


Figure 5.35 Revised Health/Nutrition component

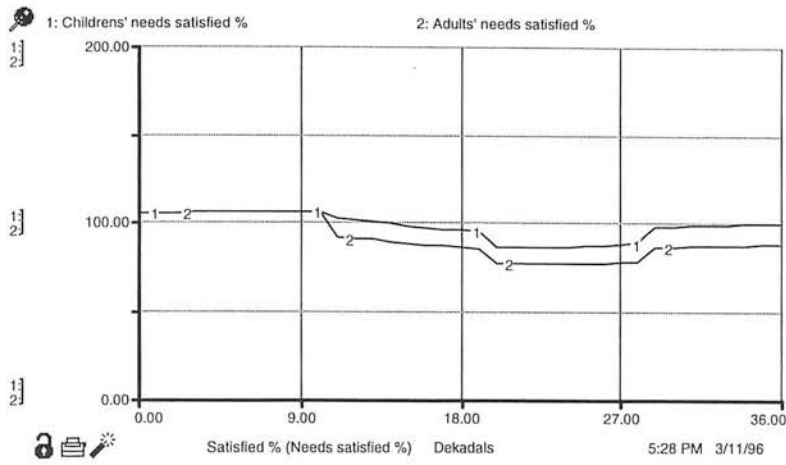


Figure 5.36 Percentage of nutritional needs satisfied

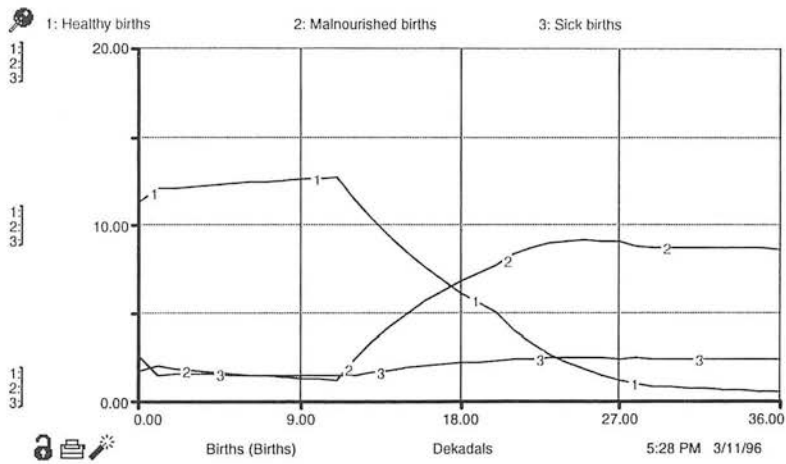


Figure 5.37 Births by health/nutrition category

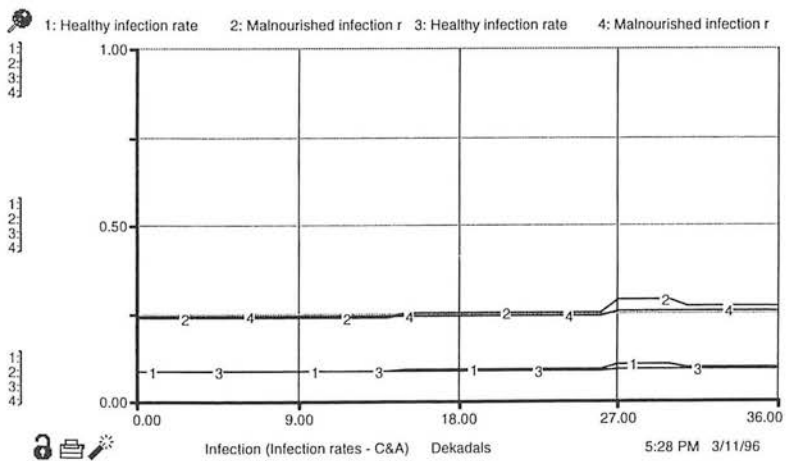


Figure 5.38 Infection rates for children and adults

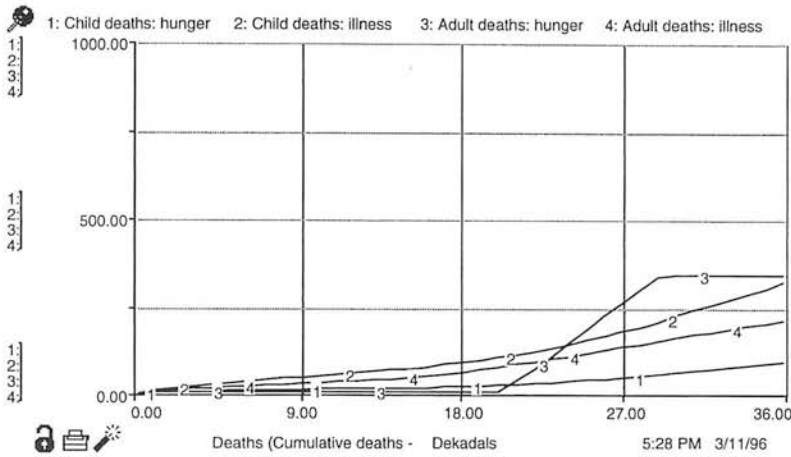


Figure 5.39 Cumulative deaths

5.9 Remarks

In the section ‘Implemented Models’ above, reference is made to the difference in scope between the two components of the system dynamic framework. This scope difference – *household* ‘Food Access’ and *community* ‘Health/Nutrition’ – was compensated in the implemented models by extrapolating from household to community by a simple multiplication of the ‘Food for Period’ by the number of households in the community. However, as noted in the comments at the end of section 5.5, the homogeneity amongst households implied by this method of extrapolation is not supported by the analyses of household survey data. The framework needs to reflect the two aspects discussed earlier: spatial dependency and heterogeneity. The use of multiple models to reflect both spatial dependencies and heterogeneities was proposed as a solution to this requirement. There were three problems with this solution:

Firstly, multiple simulations of single households are not equivalent to a single simulation of multiple households. The former, which is relatively straightforward to implement using systems dynamic methods, would effectively isolate each household for the period of the simulation (e.g. as herein, one year), other than perhaps allowing reference to some cumulative values for variables of households already simulated. Single simulation of multiple households is difficult to implement as it can only be achieved by replicating multiple instances of the model for each household and

allocating values to each initial stock and to each influencing factor, for every household. Once replicated, these household models would need to be executed in parallel to ensure that inter-household trading of grain was appropriately represented. Thus, with the potentially large number of households required to be instantiated (equivalent to the number of locations showing spatial dependency multiplied by a sufficient number of households to provide heterogeneity within each location), it would not be a feasible option within the constraints of the software and processing capability of a standard personal computer. (N.B. The sponsors of the collaborative research project, the European Commission, required that the completed model should be capable of being processed on readily available equipment, effectively constraining choice to a standard personal computer.)

Secondly, an important feature of the ‘malnutrition-infection complex’ is the interaction between health/nutrition and the sub-components of food access. A feedback mechanism, *within the household*, produces effects upon income (principally reduced capacity for work) and expenditure (health fees) from a reduction in health/nutritional status of household members. Retention of a community level ‘Health/Nutrition’ component will prevent the implementation of such mechanisms, except perhaps by the feedback of mean values for all households. A possible solution to this would be to scale down the ‘Health/Nutrition’ component to household level. (Whilst the flows used in the ‘four-box’ method are designed to transfer a proportions between categories, it would be feasible to apply probabilistic algorithms to the much smaller numbers of individuals within each category, as implied by individual household models.) However, this would again require the instantiation of multiple household models and is not feasible for other than a small number of households.

Thirdly, even if the multiple instantiations of combined ‘Food Access’ and ‘Health/Nutrition’ household models were feasible, there would remain the issue of modelling and/or reporting activity at the various levels above the household. Each level would require multiple instantiation of models of the objects therein, which themselves would contain multiple models etc. This recursive structure would be unwieldy to represent graphically and computationally inefficient to process.

The upshot of these obstacles was that, whilst the systems dynamic methodology had seemed to offer an ideal method for simulating the temporal variabilities in the local food system, it did not easily enable spatial variabilities to be represented within the designed framework. It was therefore decided to change direction and to pursue one of the alternative approaches outlined in the concluding remarks of chapter 2.

Before ending this discussion of the system dynamic framework however, the benefits to the work should be summarised. These benefits were as follows:

- **Core causal processes** – the development of the framework, from the UNICEF diagram of the ‘malnutrition-infection complex’, has spawned a greater understanding of the causal processes, both of the core interaction between food access and health and of the sub-processes: income, expenditure, own production, infection and care. The nutritional security diagram (Figure 5.2) and the graphics of the individual sub-components provided guidance for the design of each of the modules in the second framework.
- **Data definition** – the re-structuring of the UNICEF diagrams of the ‘malnutrition-infection complex’ assisted the analysis of the collected data (both from the household survey and secondary data) by relating and grouping variables by reference to the causal processes. Furthermore, both the nutritional security diagrams and the sub-components flowcharts provided detailed guidance for the data definition of the database within the second framework.
- **Denomination of process outputs** – the inter-relating of the different sub-components of ‘Food Access’ and ‘Health/Nutrition’ within the framework highlighted the need for close attention to the units in which each process operated and passed its output to other processes. The three stocks in the ‘Food Access’ component – cash, grain stocks and livestock – are denominated in Zimbabwean dollars, kilograms of maize equivalents and goat equivalents. A flow between one stock and the other, occurring as a result of farmer decision making (e.g. crop sales) or as a consequence of household behaviour or condition (e.g. purchase of animals) requires the translation from the unit of measurement of one stock to that used for measuring the other. As all these three stocks have flows into ‘Food for Period’, each also must be translated into

kilocalories when food flows occur. Subsequently, the food flows to the ‘Health/Nutrition’ component provide comparison with nutritional requirements (also in kilocalories) to determine adequacy of food available to each cohort and category and so determine changes in numbers malnourished. Infection and recovery rates are expressed as proportions infected or recovering during the current model time step. These units of measure for the different processes were substantially retained for the second phase of framework development.

- **Transactional consistency** – allied to the units of measurement, development of the systems dynamic framework highlighted the need to ensure that all transactions within the simulated system conform to the standard requirements of financial accounting i.e. that every transaction comprises two or more signed parts, the aggregate values of which must be numerically equal: ‘the debits must always equal the credits’. Enforcing such a rule, within the context of a simulation model, with different units of measurement for different variables, is an important conclusion from this part of the work.

In summary, the development of the systems dynamic framework, although flawed, has contributed substantially to the third detailed objective of this work, viz.: *‘To develop methods for inter-relating the analyses, within a modelling framework, to support the coherent representation of the processes underlying the food system’*.

6 Further design considerations

6.1 Purpose

From the concluding remarks in the previous chapter it can be seen that a change of direction occurred at this point in the work. This chapter takes stock of the various design considerations which formed the basis of the second simulation framework. The modelling of spatial and temporal variability is discussed in the light of the difficulties experienced with the systems dynamic framework. The importance of representing the hierarchy in the study district is reviewed. With reference to work by Vaze, a research associate of the collaborative project, grain trading within the study district is examined to assess the extent to which its multi-level character can be incorporated in this representation. Vaze's theoretical economic model of inter-regional trading is summarised and its implications for the modelling framework discussed. A concept of 'Communal Inter-Active Object' (C.I.A.O.) is introduced as a possible modelling design for grain purchasing and marketing. The use of behavioural rules to initiate discrete events and transactions, with these rules maintained separately from the data, is examined. This is compared to the systems dynamic approach, where processes are defined by combining data and behaviour to represent continuous flows. Simulation control is discussed, including the selection of an appropriate simulation time step and the temporal and spatial control loops required for the hierarchical structure. Rules for consistency in transaction processing: across time periods, between rules, between objects and between different levels in the hierarchy, are outlined. The chapter also reviews the appropriate structure for modelling short term factors that influence the local food system, such as rainfall, diseases and national grain market behaviour. The chapter closes with a brief review of output requirements, with particular reference to the calibration and validation of model implementations, at the level of individual sub-models and for the overall simulation.

6.2 Spatial variability

The analysis of the household survey data in chapter 2 showed that there was significant spatial dependency (at the level of 95% confidence) for the majority of

variables describing the characteristics of the sample households in relation to the three agro-ecological zones of study district. Anthropometry data exhibited some zonal dependency, particularly for the age cohorts of Under-5's, Children 5-9.9, Adult Men and Elderly. The analysis also showed that variability in anthropometry data between wards, for the two youngest cohorts, was significant at the level of 99% confidence.

As noted in the previous chapter, these spatial dependencies in the underlying household variables (e.g. cropping area, wage earners, sanitation) that influence the causal processes and also in the outcome variable – malnutrition – imply that representations of the heterogeneity of households are incomplete without explicit consideration being given to location. In other words, the use of multiple household models, as suggested in the preceding chapter, is only an adequate basis for the modelling framework, if each household instance is associated with its parent ward and agro-ecological zone.

Environmental variability (rainfall, soil quality etc.) between wards clearly affects relative harvest performance. Within each ward, however, environmental conditions will be relatively homogeneous and other factors such as availability of labour and access to draught power and fertilisers will determine individual household yields. This suggests that an appropriate modelling approach would be to simulate rainfall at ward level and use simple crop growth relationships to predict the average expected yield. This ward level average yield could then be modulated by individual household characteristics.

Changes in health status are also influenced by multi-level factors. At district level, Wright (1998) shows infection rates for measles throughout Zimbabwe are related to those in Harare, albeit with time lags depending on distance from the capital. However, the use of the national single rate for each illness group to model infection at household level will omit local conditions. Use of simulated district background rates, based upon historical morbidity and mortality statistics, as modified by local factors (similar to the mechanism shown in Figure 5.34 for the second version of the health and nutrition sub-component in the systems dynamic framework) is likely to be

a more appropriate method and is analogous to the crop yield modelling approach above.

It can be further conjectured that the spatial dependencies suggest that there exist some processes at the ward or agro-ecological zone levels, which operate in parallel to the household level processes and are probably linked to them. Examples here might be the actions of grain traders who buy/sell across agro-ecological zones in response to surpluses/shortages in wards, where inter-household trading has failed to ameliorate the individual farmers unbalanced stock positions. This is discussed further in the section below ‘Multi-level grain trading’.

6.3 Temporal variability

The analysis of the household survey data (see section 3.7) also showed that significant temporal dependency (at the level of 95% confidence), as between each of the survey rounds, for the majority of variables describing the characteristics of the sample households. Anthropometry data also exhibited temporal dependency, again for the youngest age cohorts of Under-5’s and Children 5-9.9 (at the level of 95% confidence) and elderly (at the level of 90% confidence). The only other cohort exhibiting significant temporal dependency (at the level of 99% confidence) was Adult Women.

Note, however, that these temporal dependencies are limited to a comparison between survey rounds *within the same agricultural season* and it cannot be inferred that such dependencies will exist over longer periods. Nevertheless, the analysis does emphasise the need for any simulation to take account of intra-seasonal changes and to select a time step that sufficiently small to replicate these. This choice of time step is also related to the method of simulating the interaction between processes, either as *flows* (represented by, *inter alia*, differential equations) or as *individual transactions*. The systems dynamic framework used the former method and as will be seen, the second framework, uses the latter method. This is discussed in section 6.6 below, ‘Rules, events and transactions’.

6.4 Social/administrative hierarchies in Zimbabwe

The nation of Zimbabwe is administered from the capital Harare, with eight rural provinces, each of which is divided into districts and further divided into wards. In Communal Areas, the wards are composed of ‘village development communities’ (usually referred to as ‘vidcos’). Table 6.1 below shows the administrative hierarchy in Zimbabwe and approximate demographic composition.

Layer	Households	People
Nation	2,000,000	10,000,000
Province	250,000	1,250,000
District	25,000	125,000
Ward	1,000	5,000
Vidco	200	1,000
Household	1	5

Table 6.1 Administrative hierarchy in Zimbabwe and approximate demographic composition

As detailed in Chapter 3, ‘Secondary Data’, the hierarchical structure outlined above is reflected in the units of aggregation used for data collection. Crop production estimates are based on ward-level observations, aggregated by Communal Land, further aggregated at provincial level and finally summarised in national crop forecasts. Similarly, health statistics comprise clinic data, aggregated through three levels of hierarchy: district, provincial and national.

The higher levels of this administrative structure can be traced back to the colonial period (Moyo, 1995). In 1982, following majority rule, the Communal Lands Act introduced the administrative hierarchy of province-district-ward-vidco replacing the tribal authorities in the Communal Lands with elected representative committees, thereby separating local government from traditional sources of authority. In the Communal Areas (previously Tribal Trust Lands), vidcos were superimposed on some of the traditional boundaries of tribal land units – ‘*kraals*’. These traditional or tribal systems had endured for many centuries and the *kraals*, with a small number of

families therein, represented distinct micro communities, each with a strong sense of social cohesion and shared responsibilities. The vidcos included several *kraals*, with approximately 200 households or about 1,000 people, but the boundaries were not necessarily congruent with those of traditional lands. The new administrative system effectively brought a parallel structure into being, with elected vidco chairmen and district councillors drawn from each ward operating alongside the *kraal* heads and tribal chiefs, with resultant conflicts arising between new, *de jure*, regulations and traditional, *de facto*, customs.

In the last ten years, the Zimbabwean government has given more recognition to the authorities and rights that vested in the traditional leaders, encouraging greater co-operation between these traditional and 'democratic' structures. This coincided with a policy of decentralisation, moving administration out from Harare to the provinces and districts. The traditional leaders now have an active role in the administration of local government, with the result that representatives of both systems now exert influence over the rural socio-economy, not least in the allocation of food aid and grain loans.

Such parallel structures are common throughout southern Africa and their importance to the dynamics of the local socio-economic system has been emphasised with regard to land and, in particular, communal grazing lands (Scoones, 1994). These social links prove important in decision-making at the household level in a range of activities - commercial, educational, cultural, political and care of the sick, elderly and infirm.

(In the pastoral areas of the Sahel, however, Lambert et al. (1994) have warned that such boundaries do not reflect the extent of socio-economic groups. They suggest a 'food economy' - defined independently of the administrative system - is a more effective unit, albeit that this will also comprise a multi-level structure.)

6.5 Multi-level grain trading

6.5.1 Findings from field survey

Prior to 1993, the parastatal Grain Marketing Board (G.M.B.) had an effective monopoly of grain trading in Zimbabwe. Its role was defined by statute (Rukuni and Jayne, 1995) and its operations were premised on the need to transfer surpluses from rural grain producers to urban consumers. Little consideration was given to the need to transfer grain from rural areas of surplus to rural areas of deficit. Furthermore, the Grain Marketing Board Act expressly forbade the trading of grain between the various designated rural production zones. Intra-zonal trading on an informal household-household basis was sanctioned, but the scope for traders to operate was severely curtailed and only allowed under licence from the G.M.B.. The G.M.B. set pan-seasonal, pan-territorial producer prices for most staples at the start of each agricultural season. The effect of this structure was highlighted by Rukuni and Jayne (*ibid.*). They pointed out that households in grain-deficit rural areas could only obtain food locally by purchasing processed maize flour (*'mealie-meal'*) that had been milled and packed by the large urban milling companies. These companies were supplied directly by the G.M.B., with grain purchased from rural producers. The consumer price of such flour was between 100 and 120 percent greater than the G.M.B. producer price for maize and its nutritional quality poorer than roughly milled flour from the rural hammer mills. Rukuni and Jayne estimated that rural households in the lowest income quartile who ran out of their own grain in September (approximately halfway through the agricultural year) and purchased processed maize flour suffered a 38 percent loss in real annual household income. As a result of their work, changes were made in 1993 that liberalised the grain marketing system in Zimbabwe. The main change was to allow a free market within Zimbabwe for the principal staples, with traders being allowed (without the need to obtain a licence) to buy and sell grain in and between all areas of the country. Furthermore, the G.M.B. was instructed to sell staples on demand to traders (and indeed to individual householders) at all G.M.B. depots, rather than simply onwards shipping the purchased grain to urban areas. The pricing policy of the G.M.B. continued however and pan-seasonal, pan-territorial buying prices (i.e. producer) and selling prices are still posted by the Board at the commencement of each agricultural season.

As part of the field survey of the collaborative research project, in the 1994/95 season, two research associates interviewed householder-farmers and traders to establish the nature of post-liberalisation grain trading in Buhera. Various reports were prepared by them (see Vaze et al. (1996a), Vaze et al. (1996b) and appendices to Gundry and Ferro-Luzzi (1996), (1997)). One of the research assistants, Mr. (now Dr.) P.B. Vaze, used the collected data as the basis of his doctoral thesis (Vaze, 1999). In essence, their findings were as follows:

(i) Households purchase grain from variety of sources, which vary spatially and temporally.

Households were questioned about inflows, consumption and other uses of grain (both bulk and in small quantities) at three times between February 1994 and October 1995. The results for grain inflows are shown in Table 6.2 below, taken from Vaze et al. (1996b). All quantities are shown in 'months of average household consumption' (approximately 75 kg of maize for a household of two adults and three children).

Period	Purchases	Own Production	Grain Loan		Other Sources (Gifts etc.)	TOTAL
			Scheme	Food Aid		
Nov '94 to Feb '95	1.7	0.0	0.0	0.1	0.2	2.0
Mar '95 to Jun '95	1.2	4.8	0.0	0.2	0.1	6.3
Jul '95 to Oct '95	1.9	0.0	2.2	0.1	0.1	4.3
Full Year	4.8	4.8	2.2	0.4	0.4	12.6

Table 6.2 Grain inflows for 318 households, November 1994 to October 1995. From Vaze et al. (1996b), as amended for rounding errors in original table.

The same authors report that the mean fall in grain stocks over the same period was equivalent to 1.7 months consumption, giving a total usage of 14.3 months. Of this, 1.4 months was reported as non-consumption usage, principally sales, animal feeds and brewing leaving a net total of 12.9 months. After taking account of 12 months

consumption, this leaves 0.9 months worth of stocks that can reasonably be attributed to storage losses and errors in estimating the average household consumption.

It can be seen from this table that purchases are significant in all periods of the year, but predominate during the first, so-called 'hungry' period (the drawing down of stocks is also significant during this first period). In the second period, the harvest is the main inflow. In the third period, poor yields throughout the country necessitated a support mechanism to rural families and the 'grain loan scheme' was introduced and provided the main inflow to the surveyed households.

Vaze et al. (1996a) report a spatial analysis of the detailed data underlying household purchases in column 2 of Table 6.2. They use a G.I.S. to map the source location and purchased quantities, relative to the location of the household. Three maps showing the results of this analysis are shown in figures 6.1, 6.2 and 6.3. In the maps, the arrows indicate the direction of grain movement and the thickness of the line varies according to the purchased quantity. It can be seen from these maps that sources of grain purchases were different for the two grain surplus wards close to the G.M.B. depot in the north of the district compared to the eight grain deficit wards further south. The G.M.B. and other households were proportionately more important sources of grain for the northern wards, whilst traders had greater relative importance for the southern wards. The authors argue that private traders were acting as intermediaries between the G.M.B. and remote households, due to their ability to transport in bulk, at lower costs than would be incurred by an individual household purchasing directly from the G.M.B.. Vaze et al. (1996a) also report that in wards bordering areas of surplus (e.g. on Map 2, Ward 16 borders the Wedza District, which showed good harvest surpluses in 1993/94 and 1994/95) traders also acted as intermediaries between households in surplus (in surplus districts such as Wedza) and deficit households in Buhera. Purchases from other local households in the two surplus wards also appeared to be related to higher local production - the more grain produced, the more grain was available to sell on to neighbours. The authors note that for all wards, the relative importance of the G.M.B. as a source of grain increased in the period immediately pre-harvest (February). This may be related to its policy of pan-seasonal pricing, contrasting with private traders and local surplus households which tend to raise prices during the pre-harvest period of relative scarcity.

MAP 1: Buhera District: Location, Infrastructure and Agroecological Conditions

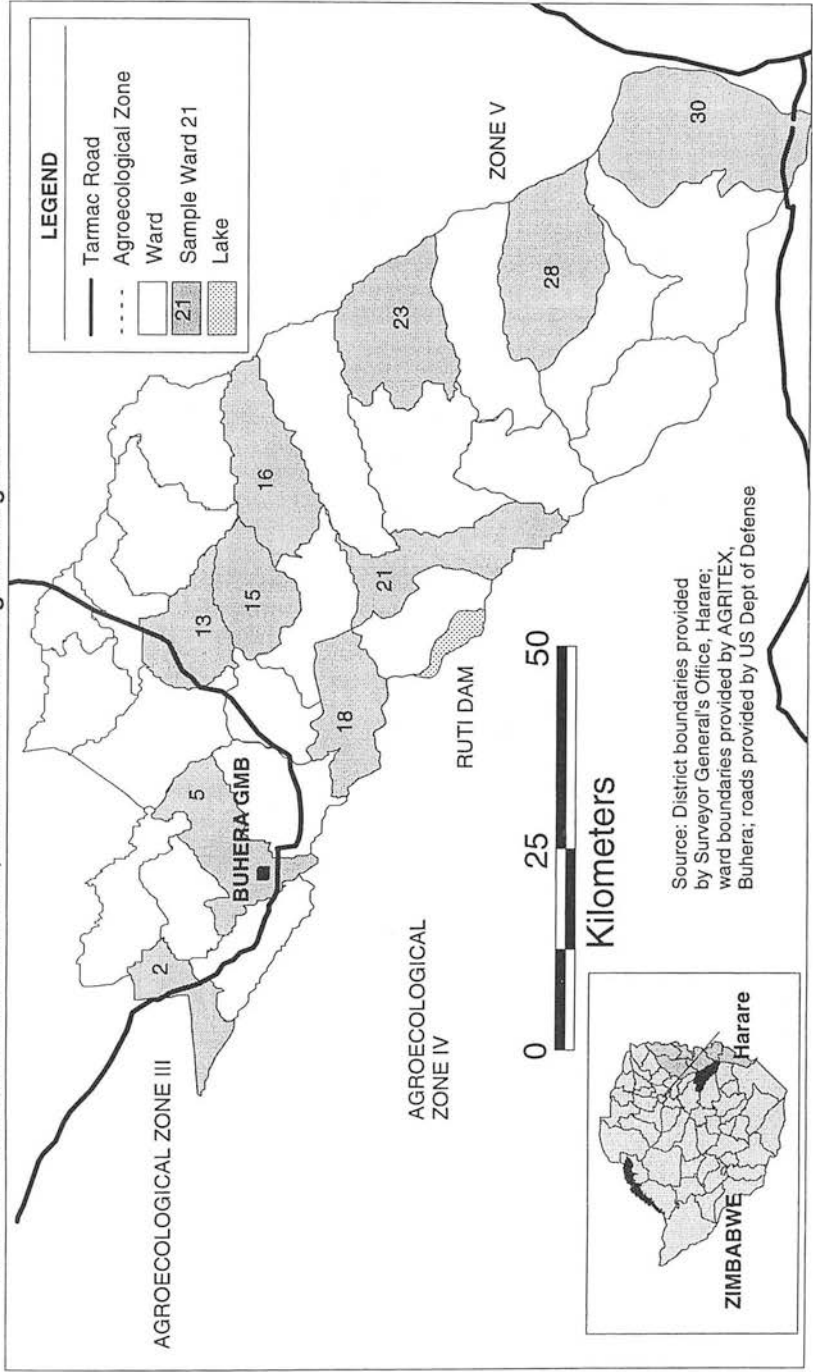


Figure 6.1 Location of household survey wards relative to G.M.B. depot in Buhera (Source: Vaze et al. (1996a))

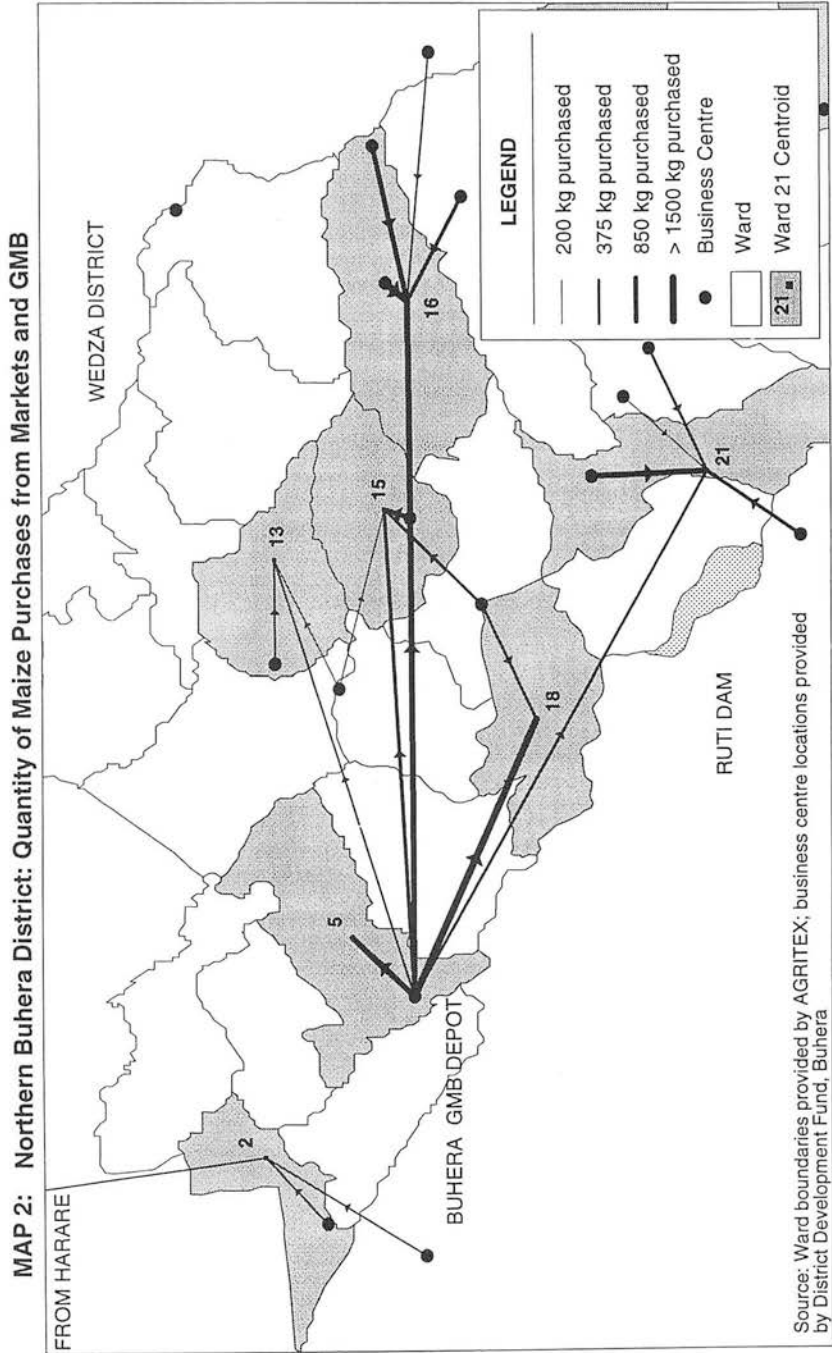


Figure 6.2 Maize purchased in sample households in northern wards of Buhera (Source: Vaze et al. (1996a))

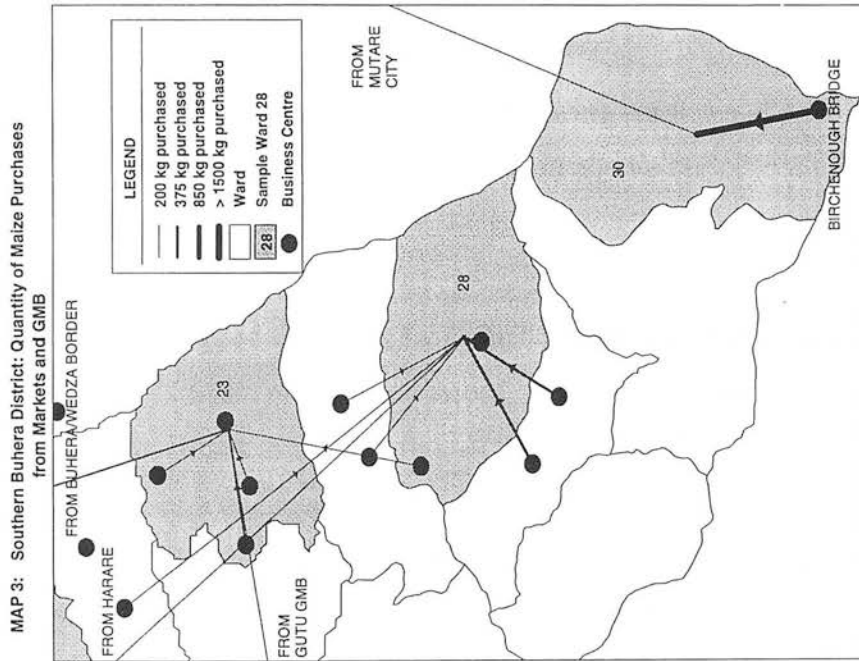


Figure 6.3 Maize purchased in sample households in southern wards of Buhera (Source: Vaze et al. (1996a))

(ii) Liberalisation has created three new grain trading channels, making five channels in total.

Pre-liberalisation, the only grain marketing channels were: *G.M.B. to urban miller to deficit household* and (within a strictly controlled zones) *surplus household to deficit household*. As a result of the changes in 1993, three new channels arose: *GMB to deficit household*, *G.M.B. to trader to deficit household* and *surplus household to trader to deficit household*.

From their fieldwork, Vaze et al. (1996a) found that the G.M.B. depot in the north of Buhera was a source of direct supply for deficit households in Ward 5 (the location of the depot). As the location became more remote, the traders became more active as intermediaries, buying from the G.M.B. depot and selling to deficit households. Alternatively, where deficit households were remote, the authors note that traders acted as intermediaries between non-neighbouring surplus and deficits households. None of these three channels would have been observed prior to the liberalisation in 1993.

(iii) The price paid for grain by deficit households was essentially determined by the G.M.B. price, as adjusted for transport costs from the nearest G.M.B. depot to the location of the household.

Vaze (1999) uses a G.I.S. algorithm to calculate transport costs for each ward/ward pair in Buhera. He then applies multi-level statistical techniques, to show that the prices paid by purchasing households are largely explained by the household's location, relative to the G.M.B. depot. He supports this finding with anecdotal evidence from the field survey that householders knew the G.M.B. price (as adjusted for transport cost for their location) even though they were purchasing from other households or traders.

(iv) Small-scale traders are encouraged into the market by their ease of access to grain from G.M.B. depots and this has the effect of undermining large traders who seek to establish high, monopolistic prices in remote areas.

Whereas large traders have relatively high establishment costs – transport, storage and networks of agents assessing market conditions – the small traders can easily enter the relatively local market of a single G.M.B. depot by purchasing in small quantities,

transporting in small vehicles or even scotch carts and selling to deficit households. There are similarly few barriers to exit the market. Vaze (1999) eloquently describes (section 5.6) the benefits: ‘this hit-and-run option available to the entrepreneur with relatively little capital acts to moderate the monopoly power of the large scale traders.’

6.5.2 Vaze’s optimal control analysis of two-region grain trading

Vaze (1999) uses the data from the field survey above, together with grain market price data from Tanzania to review the various theoretical tests of market integration and to formulate an optimal control analysis of grain trading between two regions, in circumstances similar to those prevailing in sub-Saharan countries in general and Zimbabwe in particular. Vaze’s work will be summarised herein in view of its relevance to the design of the modelling framework, in that it underpins the observations above of multi-level trading channels in the post-liberalisation grain market in Zimbabwe.

Vaze argues that as various agencies have pressed developing countries to liberalise their food markets to attain productive and allocative efficiency, so there has been a need to test these markets to see whether policy goals have been realised. Tests used to date have considered whether impediments exist to regional trade by examining time series price data from regional markets. The most commonly used model – the Takayama and Judge (1971) spatial price equilibrium model – derives arbitrage conditions for spatially dispersed markets. Two states are possible: firstly, trade in a commodity is occurring at prices determined jointly by the two markets, the difference between the two markets’ prices being the cost of transfer between them; secondly, no trade occurs between the markets and they clear independently.

Takayama and Judge observe that this latter state will only occur when the price difference between the two markets is less than the cost of transfer. Thus, the test of regional market integration is to establish the extent of correlation between time series data for the two markets’ prices. As Vaze (*ibid.*) concludes (section 3.3) ‘Price co-movements are viewed as evidence of no impediments to trade with private traders profiting through arbitrage if there are any discrepancies. Where the price of food in a pair of markets persistently moves in different directions, this is taken as evidence of

low market integration and, potentially some barriers to trading between the market pair.'

Vaze then considers how such correlation tests are carried out and in particular, reviews Ravallion's (1986) model. This assumes a dominant reference market that trades with a number of outlying markets. Ravallion shows that the price in the outlying markets is a function of the central reference market and the exogenous variables that affect that market and offers various tests for long-run, short-run and weak short-run integration. The relevance of Ravallion's model to the framework design herein is the commonly assumed structure for the economy under inspection. This takes the form of a radial food economy, with surplus grain from rural markets flowing into the central main city market (necessarily in deficit) throughout the year. Qualitatively, this central market would be judged exogenous relative to the outlying rural markets. Although the flow direction may well have been applicable to Zimbabwe's markets pre-liberalisation, it certainly has not been so since 1993, with the field work above having demonstrated the substantial amount of intra-rural trading in outlying markets. The assumption of continuous flow throughout the year is not reasonable before or after 1993.

Vaze (*ibid.*) goes on to consider other factors in relation to trading between two regional markets, in particular the temporal aspects associated with food harvests, storage and consumption over time. He develops an optimal control analysis (section 4.3), the model for which assumes two regions, each with an initial harvest of grain, the second region having a larger harvest. Consumption occurs at a constant rate over the following year. Both regions are deficit in aggregate. The two regions can trade with each other and also with a third external market that buys and sells grain at a constant price throughout the year (analogous to the G.M.B. pan-territorial, pan-seasonal prices). Vaze's analysis runs to some 24 pages and will not be detailed herein. However, the important results of his model are shown in Figure 6.4 below.

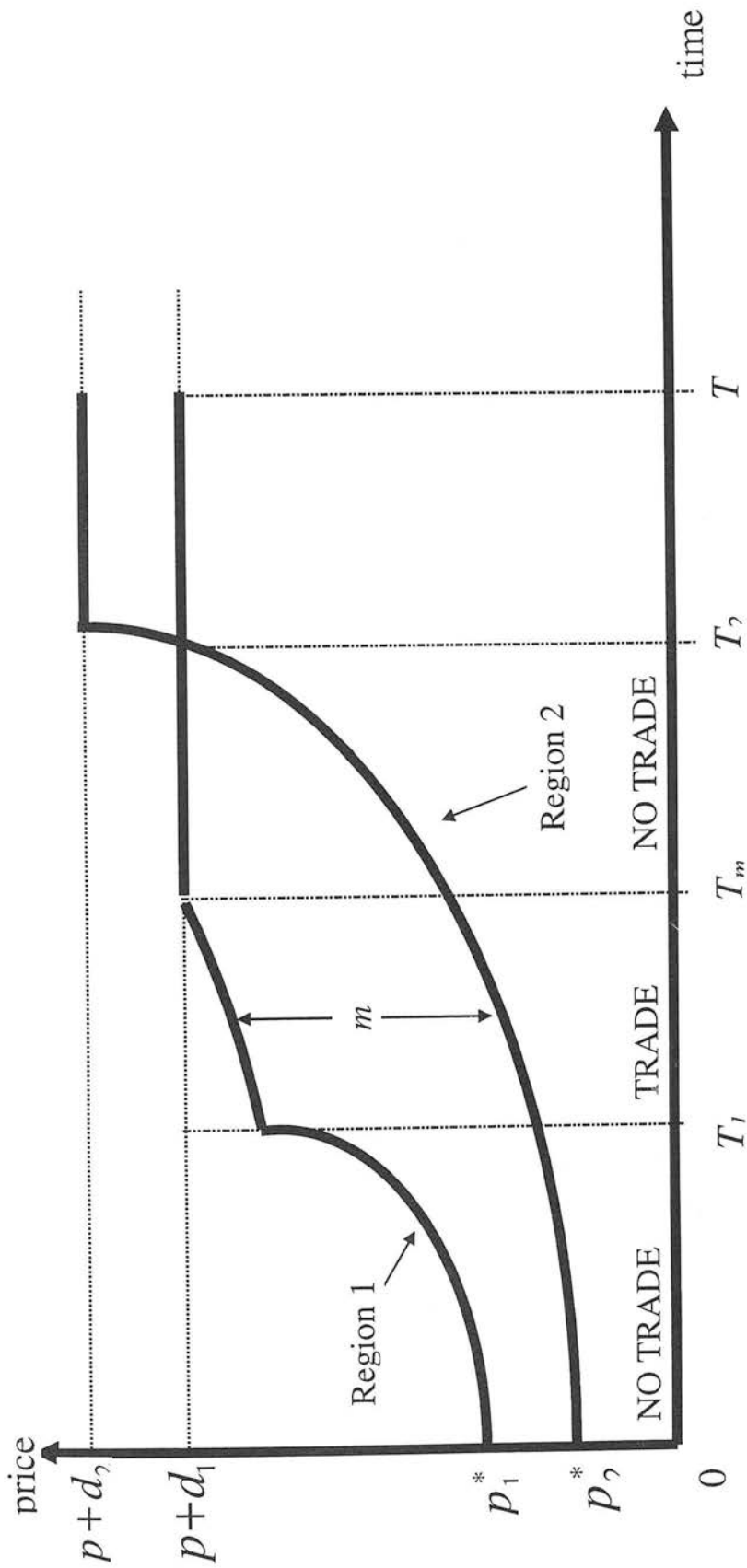


Figure 6.4 Vaze's diagram of 'Regional Prices over Time' (Source: Vaze (1999))

Figure 6.4 shows that immediately after harvest, up to time T_1 , each region has sufficient stocks to fulfil requirements internally (i.e. by surplus households selling to neighbours in deficit) and prices rise exponentially in each market as the available surplus reduces and more households move into deficit. At time T_1 , insufficient grain is available in region 1 and trading occurs with region 2 at a price m greater than the market price p^*_2 in region 2, where m is the transfer cost between the two regions. Prices continue to rise, as before until time T_m , when the price that region 1 is required to pay for food bought from region 2 (i.e. $p^*_2 + m$) equates to the cost of buying from the external market (i.e. $p + d_1$), where p is the external market price and d_1 and d_2 are the transaction costs associated with purchases from the external market in regions 1 and 2 respectively. Thereafter, region 1 purchases solely from the external market. Prices continue to rise in region 2 until surplus stocks therein are exhausted and it then also purchases solely from the external market at price $p + d_2$.

(Note that Vaze also demonstrates that if a region has good harvests and aggregate surplus stocks initially, it will be preferable to sell these to the external market rather than store for future sale in inter-regional trading.)

In summary, Vaze has effectively extended the Takayama-Judge spatial arbitrage model, to take account of storage and hence the temporal effects implicit in inter-regional trading. He has shown that regional trade will only occur for some portions of the year and at other times would not be optimal, with preferred trading occurring either internally in the region (i.e. between neighbouring deficit and surplus households) or with the external market (i.e. in the case of Zimbabwe, the G.M.B. either directly or via intermediaries). Vaze points out that the period for which regional trade is optimal depends on the price that grain can be purchased from the external market (i.e. the value of $p + d_1$) relative to the price of procuring it from the other region. With reference to the Buhera situation, where the G.M.B. is assumed to act as the external market, $p + d_1$ will be the Board's price plus the cost of transfer from the nearest depot. Assuming that the transfer cost function is linear, and the markets within the district are well integrated, it would be expected that inter-rural trading would occur for longest between those markets whose inter-market transfer cost m is lower than the transfer cost from the G.M.B.. This is likely to be in locations remote from the G.M.B., as borne out by the results of the field survey in 6.5.1 above.

6.5.3 Modelling representation

What are the implications of Vaze's work for the design of the modelling framework herein? The essence of the modelling frameworks developed herein is that they should allow individual researchers – of whatever discipline – to create sub-models that reflect their own knowledge and perspective, whilst ensuring that such sub-models interact coherently. Grain trading gives rise to particular problems in this regard in that its multilevel nature implies a series of different, channel-dependent sub-models, each of which must be linked to the levels above and below. It was therefore necessary to devise the modelling framework for grain trading to represent (albeit in a simplified way) the overall structure of the Zimbabwean grain market as revealed by the Vaze, which would allow economic modellers to incorporate their individual analyses of each level and channel. This section sets out the implications of Vaze's findings for the design of the framework and offers guidance for methods by which level and/or channel sub-models can be linked coherently. It is not intended as an economic model in its own right, but rather as a 'skeleton' to which the economists' own models can be connected.

Vaze's findings suggest that the use of the different grain trading channels varies both spatially and temporally. There is a local, household level, channel where households in surplus sell grain to those in deficit, either for cash or in return for labour. Within each community, where surplus households are unable to supply those in deficit, purchasing from sources external to the community will occur. Such sources include private grain traders and the G.M.B.. The traders appear to function in two ways. Firstly, they buy grain from the G.M.B. and transport it in bulk to those communities in deficit in aggregate, for sale to deficit households. Secondly, they buy grain from surplus households in areas of aggregate surplus and transport it to the deficit communities for sale to deficit households, as before. From the report of Vaze et al (*ibid*) it would seem that this channel is of particular importance in those deficit areas remote from a G.M.B. depot. For those areas closer to a depot, the deficit households purchase directly from the G.M.B.. These two channels can be thought of as transferring local surpluses from one area to another of deficit. The distance over which the transfer takes place will be determined by the surplus / deficit position of other communities in the same area and the costs of transfer. Thus, where harvests are poor across Buhera (as occurred in 1994-95) and there are few aggregate surplus

communities, the traders will need to buy grain from surplus communities outside the district or from the G.M.B. depots. These G.M.B. depots, although located in deficit areas, can transfer grain inwards, from regional or national warehouses, the stocks in which have been accumulated by transfer from depots in surplus areas of the country (or in nationally 'bad' years, from grain imports).

The previous paragraph describes a situation in which the majority of households are in deficit i.e. own production is insufficient to meet consumption requirements. This was the situation in Buhera District for 1994-95. However, the modelling approach adopted must also allow for the alternative position, where the majority of households are in surplus. In this situation, the surplus households will not be able to sell all their grain to local deficit households and will use the grain traders and G.M.B. to market the excess, with the channels operating in reverse of that described above.

It seems therefore that the most appropriate modelling approach is to treat the grain trading operations as occurring on four levels:

- **At household level** – those households in surplus(/deficit) sell to those in deficit(/surplus), with any excess(/shortfall) being sold(/bought) through channels operating at community level and above;
- **At community level** – the excess(/shortfall) from surplus(/deficit) households in surplus(/deficit) communities is sold to(/bought from) traders (or G.M.B. if close by) and the traders sell to(/buy from) deficit(/surplus) households in deficit(/surplus) communities within the district/province;
- **At district/province level** – the traders sell to(/buy from) G.M.B. depots in bulk and the G.M.B. depots transfer to(/from) national storage any aggregate district/provincial surplus(/deficit);
- **At national level** – the G.M.B. network transfers grain in bulk from those districts or provinces in aggregate surplus(/deficit) to those districts or provinces in aggregate deficit(/surplus), via the national storage warehouses. Where the national aggregate position is in surplus(/deficit), the G.M.B. exports(/imports) grain to redress the imbalance.

(N.B. At all levels, the net surplus(/deficit) position is not solely the difference between production and consumption for any given season and is assumed to take account of the required amounts of inter-temporal storage, appropriate for the channel. At national level, this will include the G.M.B.'s emergency reserve stocks. The net surplus(/deficit) position also includes storage and transportation losses.)

As demonstrated by Vaze (1999), the G.M.B. pan-seasonal, pan-territorial prices for purchase and sale of most staples act as reference points for traders' prices and for the striking prices of inter-household trades.

Table 6.3 below presents indicative grain prices for four communities, shown relative to the G.M.B. reference prices, for three periods across an agricultural year. The table assumes average harvest levels have occurred immediately prior to the start of the year and that the harvest expectations in January/February are also average. The communities' aggregate positions express the aggregate grain produced relative to the aggregate requirements of all individuals. Heterogeneity amongst households will be reflected in the numbers of individual households in surplus or deficit within each community. For illustrative purposes, trading has been simplified and is assumed to occur through two channels in each community, depending upon location:

- In all communities, inter-household trading will be the preferred channel for sellers and purchasers of grain, because the striking price of any bargain between neighbours will be within the margin comprising the selling and purchasing prices of the next available channel.
- For communities close to the depots, the next channel will be the G.M.B. where households will be able to sell and buy grain, at the prices set by the parastatal for the year.
- For remote communities, the only channel available, after inter-household trades, will be private traders as transport costs to the nearest G.M.B. depot are likely to be beyond the reach of individual households.

	Mar-Apr	May-Dec	Jan-Feb
	Post-harvest	Winter	Pre-harvest
Level of market activity	Very high	Low	High
Aggregate surplus, close G.M.B.			
Sales inter-household	GMBmid--	GMBmid-	GMBmid--
Purchases Inter-household	GMBmid--	GMBmid-	GMBmid--
Sales to traders	N/A	N/A	N/A
Purchases from traders	N/A	N/A	N/A
Sales to G.M.B.	GMBpurch	GMBpurch	GMBpurch
Purchases from G.M.B	N/A	N/A	N/A
Aggregate deficit, close G.M.B.			
Sales inter-household	GMBmid+	GMBmid++	GMBmid+
Purchases Inter-household	GMBmid+	GMBmid++	GMBmid+
Sales to traders	N/A	N/A	N/A
Purchases from traders	N/A	N/A	N/A
Sales to G.M.B.	N/A	N/A	N/A
Purchases from G.M.B	GMBsale	GMBsale	GMBsale
Aggregate surplus, remote G.M.B.			
Sales inter-household	GMBmid---	GMBmid--	GMBmid---
Purchases Inter-household	GMBmid---	GMBmid--	GMBmid---
Sales to traders	GMBpurch---	GMBpurch--	GMBpurch---
Purchases from traders	N/A	N/A	N/A
Sales to G.M.B.	N/A	N/A	N/A
Purchases from G.M.B	N/A	N/A	N/A
Aggregate deficit, remote G.M.B.			
Sales inter-household	GMBmid++	GMBmid+++	GMBmid++
Purchases Inter-household	GMBmid++	GMBmid+++	GMBmid++
Sales to traders	N/A	N/A	N/A
Purchases from traders	GMBsale+++	GMBsale++	GMBsale+++
Sales to G.M.B.			
Purchases from G.M.B.	N/A	N/A	N/A

Key:

- GMBsale = G.M.B. pan-seasonal, pan-territorial selling price;
 GMBpurch = G.M.B. pan-seasonal, pan-territorial buying price;
 GMBmid = mid-point price between GMBsale and GMBpurch;
 + = greater; ++ = much greater; +++ = very much greater;
 - = less; -- = much less; --- = very much less.

Table 6.3 Illustrative grain pricing for four communities

In the immediate post-harvest period, notwithstanding the aggregate community position, most communities will comprise some households in surplus and some in deficit. As shown by Vaze (*ibid.*), inter-household trading will occur, regardless of location, because both households will achieve a better price than can be obtained from traders or by travelling to the G.M.B. depot. These inter-household trades will continue until all surpluses have been sold or all deficits satisfied (or, more correctly, all deficits satisfied as far as deficit households' cash resources will allow and, where non-cash trades occur, to the point where selling households are no longer willing to accept labour for their surpluses). As Vaze shows, inter-household prices will rise exponentially in the period after harvest, before deficit households buy from traders or the G.M.B..

For communities where the aggregate of households in surplus matches the aggregate of households in deficit, the striking price should be the mid-point between the G.M.B. buying and selling prices. At this localised market equilibrium, supply and demand for the coming year will apparently be in balance and thus neither sellers nor buyers will have an incentive to engage in intertemporal storage in expectation of future price changes. Thus the striking price will be that price that offers no advantage to either party, i.e. the midpoint of the two GMB prices. Where there is more surplus grain in aggregate, the striking price should be less than this mid-point to reflect that unsatisfied sellers will only have recourse to traders' or the G.M.B. prices, both of which will be lower. (Obviously, the reverse applies where a community has deficit grain in aggregate.)

In areas close to G.M.B. depots, surplus households in communities with aggregate surpluses will market their grain at the local G.M.B., after inter-household sales have been exhausted. Deficit households in deficit communities will buy from the G.M.B., at the G.M.B. selling price, once inter-household purchasing is exhausted.

In remote areas, private traders are most active immediately post-harvest, buying grain for cash from surplus households in the communities with aggregate surpluses at a price determined by the G.M.B. buying price, less any imputed transport costs between the household location and the G.M.B. depot. (There is also a further

discount from the G.M.B. price to reflect what would nowadays be referred to as 'hassle factor' – selling to the G.M.B. may involve lengthy queuing at the depot, analysis of grain for quality checks and, perhaps most importantly, a wait of three to four weeks for payment by cheque.) For remote communities in aggregate deficit, grain purchases by deficit households will be from traders, after inter-household purchasing is exhausted. It would only be worthwhile for households to buy from the remote GMB (once inter household trading had been exhausted) if transactions costs were lower than the margin above the 'GMBsale' price being demanded by the trader. During the field survey, we noted some examples of individual households in remote villages that owned scotch carts travelling long distances to GMB depots to obtain grain and then to re-sell to other households in the village. This is one type of informal, temporary trader that will come into existence when deficits are large and widespread and the usual traders have sufficient demand to remain in the more populous and less remote areas.

In the winter months following a good harvest, inter-household trades will occur in all communities as deficit households receive cash from remittances or casual earnings to allow them to purchase grain from their neighbours in surplus, or as surplus households engage labour from neighbouring deficit households in return for grain. With a good harvest, the striking price for inter-household trades will remain below the mid-point of the G.M.B. reference prices.

In the winter months following a poor harvest, there will be few surplus households remaining in all communities and deficit households will resort to purchasing from traders or the G.M.B., depending upon remoteness, as before. Any inter-household trades that do occur will be at striking prices above the G.M.B. mid-point, rising in very poor years to above the G.M.B. selling price, but below that at which private traders will sell. In remote deficit communities, where no surplus households remain available to meet demand from deficit households, purchasing will only be from traders. These traders will be able to charge prices above the G.M.B. selling price as the alternative for households is to arrange and fund the transport for purchase of grain from distant G.M.B. depots. Poor households will also not have the resources to purchase in bulk that make the costs of such transport an economically feasible option. In communities closer to G.M.B. depots, prices from traders will remain

much closer to the G.M.B. selling price as a G.M.B. purchase is a feasible option even for poor, deficit households.

During the post-harvest and winter periods, Vaze et al. (1996b) report that sales and purchases by households are influenced primarily by an assessment of whether current stocks are sufficient to meet requirements for the remainder of the year. However, by January, harvest expectations for the current growing season are becoming clear. Where households have pessimistically retained surpluses, these are now sold when expectations are good. In these circumstances, with deficit households also expecting good harvests and being able to supplement stocks with 'green' (partially ripened) maize, inter-household trades decline. Similarly, traders are reluctant to buy in stocks when harvest expectations are good and thus the G.M.B. becomes the buyer of last resort at the buying price set in the previous year. (Historically, in average and good years, the G.M.B. has experienced surges in grain inflows in late January, February corresponding to this off-loading of stocks by surplus households.)

This commentary on trading and prices emphasises that Vaze's model, for use within the modelling framework developed herein, will require extension to incorporate the dual prices set by the G.M.B., but that the core idea of a central market being a reference has validity.

As an example, Figure 6.5 overleaf shows the market (cf. inter-household) price of maize in Manicaland during the 1992/93 season. Note the fixed G.M.B. prices of Z\$8 per 20 litre tin (producer or G.M.B. buying price) and Z\$16 per 20 litre tin (G.M.B. selling price), representing a 100% margin. Referring back to section 3.6, it can be seen that 1991/92 was a very poor harvest in Buhera (with the similar results in the other districts of Manicaland). Thus the majority of households were purchasing grain at the end of that season (around '9204' to '9206' on the chart in Figure 6.5) and the market prices remained high.

As noted in section 6.5.1, G.M.B. operations were not liberalised until 1993. Prior to this (i.e. including the 1991/92 and 1992/93 seasons shown in figure 6.5) the purpose of G.M.B. operations was to transfer grain from rural areas (assumed to be in surplus)

to millers in urban areas. Little consideration was given to inter rural transfers, with G.M.B. depots refusing to sell grain locally, despite a selling price being posted. After the inter household purchasing channel was exhausted, householders in deficit rural districts only had the options of purchasing maize at local markets from licensed traders or purchasing processed maize flour (*'mealie meal'*) from local shops. Thus the G.M.B. selling price shown in figure 6.5 is to some extent a false reference point for market prices in Buhera. Traders' maize prices would have been set relative to the producer price and this margin up to '9303' remains relatively constant, reflecting the transaction cost of obtaining supplies outside the district. However, in 1992/93, rainfall was normal (see Figure 3.2). After the harvest at time '9303', the district moves into surplus and most households become sellers. As sellers, the reference point is still the G.M.B. producer price with the market price being below this. The margin between market price and producer price is now much lower, reflecting a lower transaction cost of selling at a G.M.B. depot within Buhera. This behaviour, where market prices are tied to the dominant parastatal's prices is in line with the Vaze model.

Note that Figure 6.5 gives no information about direct inter-household trades and on the basis of the arguments above these would have been at prices between the local market prices and the G.M.B. producer prices, with the opportunity cost for surplus households being closer to the local market price. For the 1992/93 season this suggests prices of around Z\$18 until after the good harvest when the district moved into surplus. Coupled with the increase in the G.M.B. producer price in '9304', this effectively 'pegged' the opportunity cost at which surplus households could sell locally within Buhera, thus indicating an inter-household price of around Z\$13.

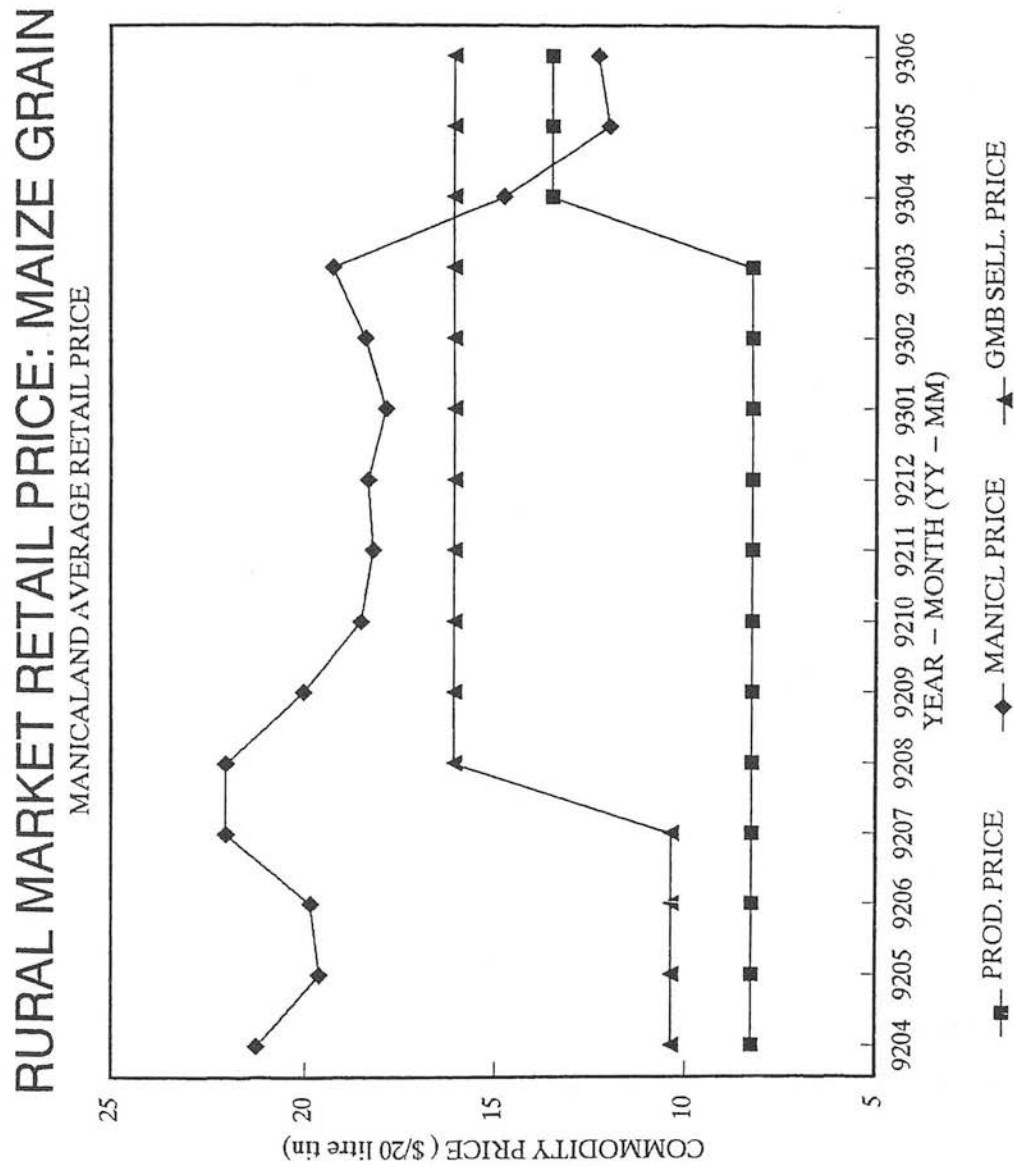


Figure 6.5 Rural market maize prices for Manicaland Province 1992/93. (Source: National Early Warning Unit, Harare)

Although this description of grain trading and pricing mechanisms is insufficient to provide the detail required to implement a simulation model, it provides guidance for the framework design. There are three important implications:

- Firstly, trading can occur within each of several different levels of the food system and results in flows of food between the different ‘objects’ within each level. The trading channels at the ‘higher’ levels of the system serve to distribute food across wide areas, whereas the ‘lower’ level channels are mechanisms that provide essentially local distribution. All should be explicitly represented in the framework.
- Secondly, trading links between levels enable local imbalances of food to be corrected by market mechanisms that transfer food from communities in surplus to those in deficit. These links should also be represented explicitly.
- Thirdly, in any year pricing is influenced by five main factors: (1) the prices set by the G.M.B. at the start of each agricultural season; (2) harvest performance for the previous year; (3) expected harvest performance for the current year; (4) location at which the transaction occurs, relative to the network of G.M.B. depots; and (5) the type of trading channel. The weightings of each of the factors will vary during the year.

This suggests that a multi-level modelling framework will provide the best representation of the food system, with the simulation proceeding in such a way that processing of levels is connected and synchronised. Each level cannot be modelled in isolation and linked at the conclusion of the simulation. Both trading and pricing are dynamic mechanisms, which also vary with location. The framework must ensure that the factors influencing these mechanisms can be implemented in such ways as to reflect their inherent temporal and spatial variabilities.

6.5.4 'Communal Inter-Active Object'

The closing remarks of the last section and the four-level (household / community / district / national) structure outlined are intended to serve as a general guide for the modelling framework. It is applicable to the food system in rural Zimbabwe and, indeed, other African countries with non-pastoral agriculturally-based economies. The four levels encompass the full socio-economic structure of the country, whereas the work herein is concerned with the food system at district level and below. Therefore, in the description of the concept of 'Communal Inter-Active Object' (C.I.A.O.) that follows, its application to the representation of the local food system will be emphasised, but this is not intended to suggest that it could not be extended to include national level trading.

To convert the guidance in the previous section into a more formal representation, it is necessary to consider how individual trades of grain, at each level, will be instantiated within the simulation and to define the various 'actors' that will make such trades.

The first requirement is to define the levels at which the implemented models will operate. This work is concerned with '...the local food system for a *rural community* in Zimbabwe' and will therefore emphasise the processes occurring within the level most closely equivalent to a community. As has been discussed, the food systems of communities cannot be represented in isolation and must include the relevant processes occurring in their constituent households and in the districts or provinces areas in which they are located.

The choice of 'community' could be several socio-economic units: *kraal*, vidco or ward, but is constrained by the availability of data for each. As no statistics are available for the traditional land units, *kraals* are not a feasible choice. In Zimbabwe, the closest identifiable administrative unit to a community is the vidco and it was thought that this would be the appropriate level on which to focus the second framework. However, it was subsequently found that apart from basic census demography (which was subsequently found to be in error) there are limited data aggregated by vidco, including most of the variables relating to food and health. Accordingly, 'ward' was selected as the community level, being an easily identifiable

unit in most secondary data. There are thirty-two rural wards in Buhera District, each containing approximately 1,200 households.

A feasible three level structure could therefore have been household/ward/district, but the analysis of household survey data had already shown that significant spatial dependencies existed for the three agro-ecological zones. These were therefore retained in the modelling levels used for the second framework, to give a four level structure within Buhera District of: household / ward / agro-ecological zone / district.

(By way of comment, it may seem that the selection of levels for the framework is somewhat arbitrary. Indeed, for different countries, different choices of levels will surely be appropriate. The important guidelines are to select for use as levels those socio-economic units or areas that the population themselves recognise as having distinctive characteristics and that are also used by government and other agencies as aggregating units for data reporting purposes.)

The definition of the various actors is superficially straightforward, the actors are the households in each community, the private traders and the G.M.B.. Note that 'private traders' can take many forms: itinerant traders, grain merchants at local 'growth points', millers and *ad hoc* traders who perhaps have other employment giving them access to transport. To reflect the heterogeneity of the households and other actors, it will be necessary to represent them in the simulation either by multiple instantiation or by classifying the study population, based on the household survey, into its principal types or clusters and creating a small number of representative households etc. for each ward. However, with a small number of representative households in each ward, inter-household grain trading would be difficult to implement. Even if implementation was achieved, it would be limited in extent. This is because, in any one simulation time step, there would probably be only one or two households in each ward having surplus/deficit grain stocks and able to engage in trade with a neighbouring household.

Thus, to retain the maximum heterogeneity, the method adopted for the representation of households, traders etc. in each level was multiple instantiation. However, this also presented difficulties for implementing of inter-household grain trading, but at the

other extreme to having too few households. With many households, inter-household grain trading will produce an effective market for both sellers (the households in surplus) and buyers (the households in deficit), but the modelling framework requires an efficient method to bring about individual trades.

The obvious solution would be to incorporate a procedure to ‘match bargains’, whereby a household wishing to sell surplus grain in any simulation time step is matched to a household, in the same ward, wishing to purchase the same quantity of grain (and having the cash to do so). Difficulties will arise in this dynamic matching process as the number of households in each ward increases. This is because within one ward, after partially simulating the first household to the point where surplus/deficit position has arisen, the simulation must be temporarily stopped. Every other household in the ward must then be simulated to the same point and temporarily stopped, after recording each household’s surplus / deficit position.

With all households’ surplus / deficit positions known, the procedure to match buyers and sellers can then be invoked. Even assuming the use of a single striking price for all trades (within one ward, for one time step) this procedure will be relatively complex to program and computationally intensive. Following matching, any households with unsatisfied positions (and these will always occur unless the ward aggregate surplus/deficit position is itself exactly balanced) will be required to sell / buy by matching with traders.

Only after completion of these steps in the matching procedure can the simulation of all households be re-started. Thus, not only is the matching procedure itself a substantial computational burden, but the need to ‘start-stop-start’ the main simulation, for all households, in every ward, in every agro-ecological zone at every time step would produce implemented models that would have required substantial computing resources beyond the facilities available to the collaborative project. (See the ‘Remarks’ section of the previous chapter for the reason for this constraint.)

It is clear that the grain trading channels and their operating characteristics are an integral part of the local food system. However, the problems identified above would have remained an obstacle to further progress with the design of the second

framework unless the representation of grain trading operations was simplified. This simplification in representation was needed to reduce substantially the complexity of the trading procedures, whilst retaining the essentials of the hierarchical selection of the trading channels. The requirement to be met by any simplification was that the resultant approximations in food flows would still 'be adequate for the intended purpose' i.e. would meet the criteria for a simulation model laid down by Schlesinger, (referred to in section 5.3, 'Resource stocks, flows and influences').

The simplification considered was to replace the direct inter-household trading with an indirect procedure. Within each ward, the dynamic matching of surplus and deficit households would be replaced by transferring all household trades to a central trader or market 'clearing house'. This central trader would accept all offered trades from the constituent households, regardless of any resultant imbalance between surpluses and deficits. In other words, at each simulation time step, any household having surplus or deficit grain stocks could sell or purchase grain, limited only by the household's stocks (for a sale) or the household's cash (for a purchase). The central trader would effectively act as a clearing house for the ward and its stock position at the end of each time step would therefore be the ward's aggregate surplus or deficit position.

The effect of this would be that the central trader for the ward would itself be then in surplus (*or deficit*) and would be required to trade with another ward's central trader, within the same agro-ecological zone, that was in deficit (*or surplus*). However, at the level of agro-ecological zone, the dynamic matching of all wards' central traders would again cause a similar problem to that for the dynamic matching of households, albeit on a smaller scale. To overcome this, the central trader procedure could also be applied to trades between wards within each agro-ecological zone.

It will be observed that the adoption of this simplification will replace the various 'real' actors, at each level of the hierarchy above household, with some form of collective object having a standard, recursive structure. These collective objects for each level will be comprised of collective objects from the hierarchical level below, trading with a central trader. The use of these objects at every level should mimic the actions of 'real' traders and the G.M.B. in transferring grain from areas of surplus to

those of deficit. At the top level, national central trader will need to export/import grain to resolve any aggregate surplus/deficit position.

In discussions with the collaborative researchers, this recursive object was referred to as a ‘Communal Inter-Active Object’ or C.I.A.O. and is illustrated in Figure 6.6 overleaf, shown as applied to the agro-ecological zone and the ward levels of the hierarchy.

The C.I.A.O. concept in Figure 6.6 shows, in the upper part of the diagram, the central trader in agro-ecological zone z_1 , trading with each of eight wards $w_1 - w_8$ through the central traders of those wards. For ward w_4 , the lower part of the diagram illustrates the trading between the central trader of w_4 and its constituent households $h_1 - h_8$. (N.B. An arbitrary eight zones/wards have been used for illustrative purposes and in practice, the number will vary across and between levels.)

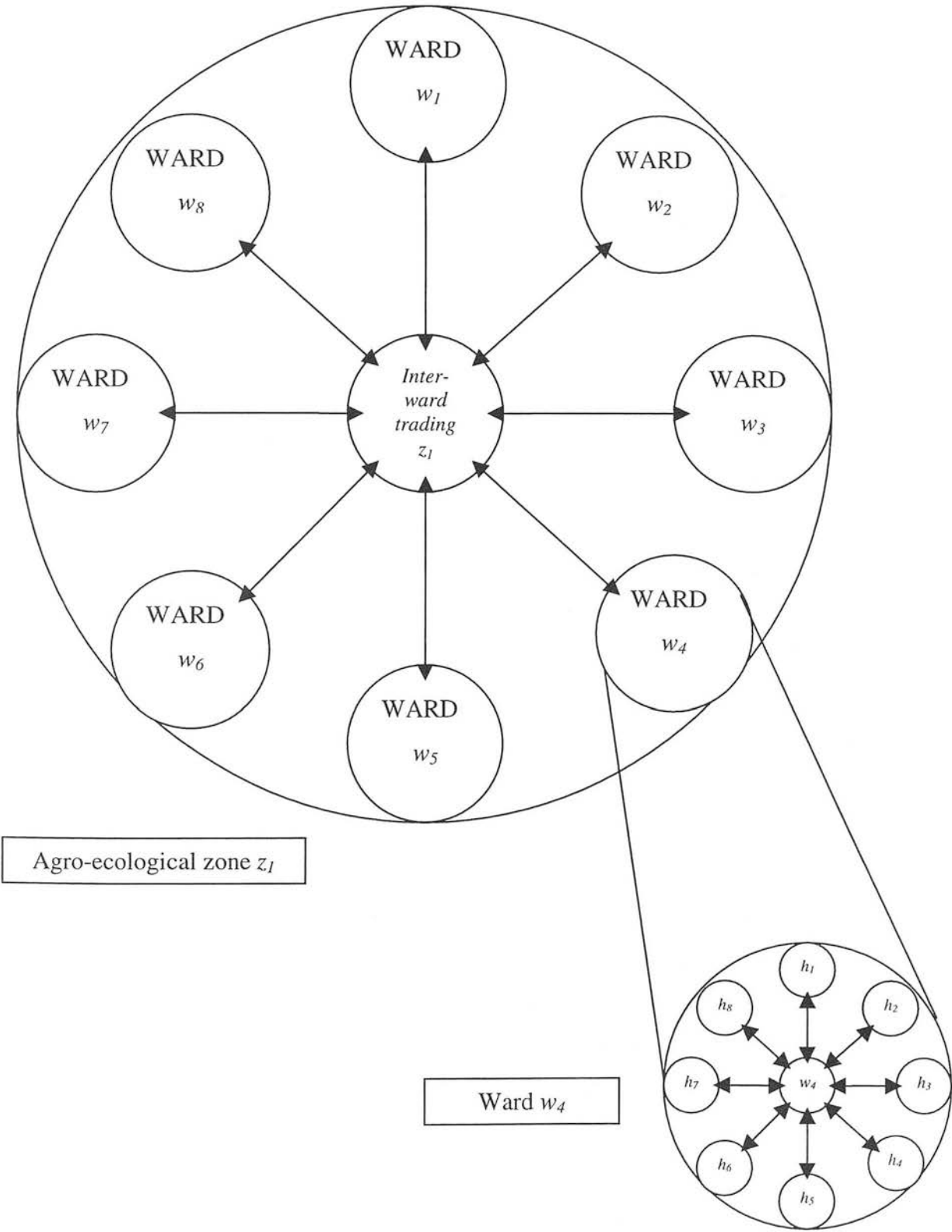


Figure 6.6 Concept of 'Communal Inter Active Object' as applied to two levels of the administrative hierarchy of Buhera.

Prices are one aspect requiring further discussion of the simplification based around the C.I.A.O. concept. In the previous section, the setting of striking prices for trades was seen to be influenced by five main factors: G.M.B. prices, the previous harvest, the expected harvest, the location of the trade and the trading channel used. All five factors differed in their relative importance across the year. The fifth factor, trading channel, is of particular importance in relation to the C.I.A.O. concept. It was noted in the previous section that it was in the interests of both selling and buying households to choose inter-household trade as the preferred trading channel. This was because the striking price of the bargain would be around the mid-point of the two G.M.B. prices and certainly within the price spread offered by a trader. Using an artificial central trader as a clearing house for all trades will prevent identification of such inter-household trades as all trades are executed without limit. Thus, where a ward is in aggregate surplus or deficit, some of the simulated trades through the central trader would in practice have been inter-household and some would have been with real traders. There would be a significant price difference between these.

It is suggested that this problem can be ameliorated by combining dynamic pricing models which incorporate intra-seasonal price variation and take account of the first four factors and judicious selection of the time step of the simulation. Vaze (1999) has already developed such models based on the data from the household survey and grain market prices collected contemporaneously with that survey. These could be used to set selling and buying prices dynamically for trades at district level (i.e. between zones) and for trades at zone level (i.e. between wards). From the commentary on pricing in the previous section, it can be assumed that within each ward, the inter-household price would be approximately the mid-point of the inter-ward prices. If the simulation model has small time steps in relation to the periods of high activity in household grain marketing (i.e. the two months each for post harvest and pre-harvest), the aggregate surplus/deficit position of any ward at time $t-1$ can be taken as a first order approximation of the position at time t . On this basis, the ratio of household sales to household purchases by the central trader in time $t-1$ can also be taken as an approximation of the expected ratio in time t . If this ratio is exactly 1, then the ward in aggregate will be in balance i.e. no surplus or deficit and all trades will have been through the inter-household channel at the ward inter-household price. If the ratio exceeds 1, then the excess will be the proportion of household sales

through the trader channel, executed at the zone level selling price. If the ratio is less than 1, then the shortfall will be the proportion of household purchases through the trader channel, executed at zone level buying price. These ratios could then be used to prorate the prices in time t for each individual household sale or purchase.

In summary to this sub-section, the use of the C.I.A.O. concept would undoubtedly be an approximate representation of the grain trading and pricing processes in the study district. However, with the addition of the pricing methodology above, it is probable that this approximation would not result in inaccuracies of such a magnitude as to invalidate the use of the C.I.A.O. concept within the context of a more comprehensive simulation model of nutritional security. The potential benefits of the concept are substantial improvements in the efficiency of the implemented simulation models, enabling the applications to be carried out on standard personal computers.

6.6 Rules, events and transactions

In the closing 'Remarks' of the previous chapter, it was observed that whilst system dynamic modelling packages are inherently designed to analyse temporal variability, they do not readily take account of the spatial variability, the hierarchical structure of the local socio-economy or the diversity amongst households.

Equally important to the design of the second framework was the recognition that many of the causes underlying the 'malnutrition-infection complex' are poorly represented by continuous processes. In reality, these causes comprise a series of discrete events, initiated by the complex rules and decision making of household socio-economic behaviour. The inherent discontinuities in such rules and behaviour are not easily encoded using the stocks / flows methodology of systems dynamic modelling. A more direct method of rule-building was thought to be the preferable alternative.

In the section above, the system of grain trading was described and a fundamental feature was the discrete nature of the sales and purchases by households. In trading, grain does not 'flow' in a continuous stream from (*to*) the household, any more than the cash that has been received (*paid*) for the sale (*purchase*) can be said to be

‘flowing’ in (*out*) of the household. These movements of grain, cash and other tradable resources are occurring in discrete parcels and the economic exchange is a discrete event, brought about by decisions of both parties to the transaction.

Within the household, many other aspects of behaviour are best thought of as multiple states of action or of inaction, which are changed as a result of changes in values of the influencing variables. Examples are work activity, allocation of resources, seeking treatment for illness etc. For these and the previous examples of socio-economic behaviour, it was decided to structure the second framework to enable models to be implemented through the use of rule-based representations, acting at each time step upon the behavioural states determined in the previous time step.

However, not all the processes within the household are continuous. In particular, those that relate to the physiology of humans, animals and plants – growth, nutrition, sickness and recovery etc. – are accurately represented by continuously changing variables. But, just as the systems dynamic methodology approximated discrete events by flows, so these continuous physiological processes can also be approximated by changes of behavioural state, brought about by changes in values of the influencing variables. For example, nutritional well being varies continuously and is measured by (in adults) body mass index (B.M.I.). However, subjects are classified by their nutritional status e.g. malnourished, not malnourished, obese. These classes can be represented as discrete states and, using the same procedures as above for socio-economic behaviour, the changes in state between consecutive time steps can be brought about by the application of behavioural rules.

Thus, the first important distinction between the two designs was the shift from flow-based continuous process modelling to rule-based discrete event modelling.

A second important distinction between the two designs was also made. In the systems dynamic framework in the previous chapter, the various sub-components of ‘Food Access’ and ‘Health/Nutrition’ were represented by expressions in the modelling language (Stella II). This did not facilitate the separation of data that described the households and communities in the simulation from the values of

variables within each process, as entered by users as part of their individual model implementations.

It was therefore decided that a modular approach to the structure of the second framework should be adopted. This would enforce separation between data (the various behavioural states and conditions of households, communities etc. at any given time step) and the model implementations themselves (the various sub-components of the ‘malnutrition-infection complex’ as encoded by sets of behavioural rules). Enforced separation between data and model would ensure that the following issues were correctly addressed:

- **Data corruption** – the starting values of the data describing the households, communities etc. for each run of a simulation should be unalterable by the model itself. This will ensure that accidental data corruptions do not occur and consistency between simulation runs is maintained;
- **Intermediate data values** - any changes in the values of the data describing the households, communities etc., during the course of the simulation, should be stored separately from the starting values and referenced to the time step to which they relate. This will ensure that any post simulation analysis or graphical display can access all simulated data values and not just the start and end conditions;
- **New data** – changes to the starting data describing the simulated households, communities etc. should not require the use of the modelling code. This will enable new starting conditions or new study populations to be entered without accidental changes to the model occurring.

6.7 Simulation control

The shift in emphasis from process to discrete event modelling removed the simulation ‘timekeeping’ that had been present in the first framework design that was an inherent feature of the linked stocks / flows representation of the system’s dynamics. The ideas in the section above, especially the separation of data from the behavioural rules, took away the tightly bound representation of the food system. It

was therefore necessary to consider at this point how temporal and spatial control could be incorporated within the revised design.

Temporal control of the simulation defines how the simulation period (i.e. the elapsed time over which the events occur) should be broken down into individual time steps, during which the rules will be ‘fired’, causing events to occur and changes to be made to the data detailing the behavioural states, as set in the previous time step. The order in which rules ‘fire’ is also part of temporal control. As an example, within a household, the firing order of income rules and expenditure rules will determine whether current expenditure has the benefit of the current time step’s income.

Definition of the simulation period and of the simulation time step should also be made by reference to the intended application. Herein, the food system is being simulated over a complete agricultural year and therefore the time period is twelve months. However, using a monthly time step may cause problems when the simulated grain trading activity is at its highest as all households will be active in the two time steps immediately post-harvest. This will cause ‘lumpiness’ in the grain trading, with sharp increases in March (the first post-harvest month) and sharp falls in May (the time step after the second post-harvest month). If the procedure for proration of trades between inter-household and trader channels is adopted to apply to pricing by channel, these sharp changes in trading volumes would pose problems. For other events, a time step of one month is also probably too long. In particular, these events include sickness and crop growth. For sickness, where the length of time ill is frequently less than one month, a monthly time step would be too coarse. The simulation would have to average individuals’ health statuses, with the result that some would be shown as being in a state of ‘ill’ when they were not and some in a state of ‘well’ when in fact they were still ‘ill’. Quality of crop growth determines the extent to which farmers sell stocks held back after the previous harvest as insurance against crop failure in the current year. An important aspect of modelling crop growth is damage due to heat stress in periods without rain. All the principal staples are affected. For maize, during the early critical growth stages, the plant cannot survive without water for more than twenty days. Thus rainfall (a short term factor – see below) must be simulated in smaller time steps than one month to ensure that crop failures due to lack of rain are not understated.

Against the need for a shorter time step, two arguments should be balanced. Firstly, in discrete event modelling, artificial time ‘slicing’ may result in less coarse behaviour, but will not produce greater accuracy in the system’s responsiveness, as occurs with system dynamic modelling where differential equations are used to control flows. For discrete events, accuracy will only improve if the separate values of the data having temporal variability relate to the selected time step and are not simply approximations thereto from data collected at a larger interval. Secondly, smaller time steps imply greater processing requirements. For simulations with a large amounts of data and/or rules, the processing time will increase almost linearly as the inverse of the time step selected – halving the time step will double the simulation processing time.

The result of these deliberations was to select a time step of a *dekad*, approximately ten days. This was chosen because the rainfall data that are available for Zimbabwe are either derived from satellite images (‘Cold Cloud Data’) or from meteorological stations. In both cases, cumulative rainfall data are recorded for each month in three periods: (1) days 1 – 10 inclusive; (2) days 11 – 20 inclusive; and (3) the remainder of the calendar month (i.e. a period between eight and eleven days, with a mean of 10.17 days). This time step is also suitable for periods of active grain trading and for the duration of illnesses.

Spatial control of the simulation is required to ensure that the behaviour of each actor or object within each level of the hierarchy is modelled during each time step, in a consistent order and that any cross-level events or transactions are accounted for correctly. With the four level hierarchy of household / ward / zone / district outlined previously, the control essentially follows the data structure, causing each level’s rules to fire for each actor or object within that level. The processing order can be thought of as a series of nested loops:

- **Outermost loop** – timing control, dekads 1 through 36;
- **District** – 1 only;
- **Agro-ecological zone** – zones 1 through 3 (for Buhera District);

- **Ward** – wards 1 through w , where w is the total number of wards in the zone currently being processed;
- **Household** – households 1 through h , where h is the total number of households in the ward currently being processed.

Temporal control of processing occurs sequentially for each of the dekads 1 through 36, as governed by the outermost loop above.

Spatial control is effected by the remainder of the loop structure. In each dekad, processing starts at household 1, within ward 1, within in zone 1, within the district, continuing until all h households in ward 1 have been processed, after which the ward level processing for ward 1 is carried out. Processing then moves to ward 2 (still within zone 1) and all households therein are processed, followed by the ward level processing for ward 2. This continues until all w wards within zone 1 have been processed, together with their constituent households, at which point zone level processing for zone 1 is carried out. Control then moves to zone 2 and the processing continues as before. Upon completion of all zones, any district level processing is carried out. Control then passes back to the temporal loop to increment the dekad count.

Thus by processing every actor or object within each layer, for every dekad, the complete processing of the hierarchy, for the year, is accomplished.

(This method of recursive, hierarchical dynamic simulation is untried in the context of food systems research, but has parallels in recent work on multi-level modelling. In applied social and educational research, micro-level units, such as workers or students, are nested within macro-level units, such as industries and schools. Where implementers of the second framework are using statistical analyses to develop their behavioural rules, the estimation of the co-efficients in such functions must take into account the fact that the random error term combines the sampling error associated with each tier of the model (Goldstein, 1987). Thus, care needs to be taken as households from one ward may be more similar to each other than to households taken from other wards and the assumption of independence of observations would be

invalid. Vaze (1999) uses Goldstein's methods to demonstrate that the price of maize in each sample ward was largely determined by the G.M.B. producer price and the distance from the nearest depot (as a proxy for the transfer costs from depot to ward.)

6.8 Processing consistency

In the 'remarks' in the previous chapter, two benefits from the first framework were noted. Firstly, the need was recognised for outputs from the various sub-components to be consistent in their use of units. Where translation from one unit to another was required upon transfer to another sub-component, care should be exercised to ensure that the basis of the translation was consistent throughout all sub-components.

Secondly, where transactions occurred e.g. sales or purchases of grain, the affected stocks of both the seller and buyer should be required by the framework to be reconcilable before and after the transaction.

This requirement for consistency in processing is considerably eased by the planned separation of data and behavioural rules discussed above. Nonetheless, some specific points of design consideration are as follows:

- **Across time periods** – with a time step of one dekad and the processing order outlined in the previous section, the data for each actor or object will be updated 36 times during the course of the simulation period of one year. One approach to recording these changes would be to have a single field that held the current time step's state, value or running balance (the latter being for accumulating fields, such as cash or stocks of grain). Such an approach would be problematic for two reasons. Firstly, validation of rules would be difficult if only the starting and closing values of the data were available. Secondly (as noted in the previous section), simulation output would be restricted to the same two values, so any mid year positions could not be reported or analysed. The preferred approach would be to store all intermediate values and for the accumulating fields, to store the aggregate transactions changing the balance in addition to the balance itself e.g. for a household's cash in period t , the aggregate income, aggregate expenditure and balance for the period should be

recorded, rather than the simple balance. Again, this will aid validation and ensure that detailed *ad hoc* enquiries can be supported, post processing.

- **Between behavioural rules** – as rules fire within the processing of one object e.g. household, it will be necessary to change the units to give effect to the behaviour in the data stored for the object. For example, the reclassification of household members from ‘healthy’ to ‘sick’ by the application of an infection rule, may be followed by a rule determining labour resources on the basis of household members’ health and nutritional status. This should have an explicit recognition that ‘sick’ for the period has an equivalence in days of labour lost. In every time step, therefore, the total ‘days’ resources will always remain the same for the same household (barring death), with some days classified as ‘available for work’ and some classified as ‘lost due to sickness’ (or malnutrition etc.). This consistency will again aid model validation and improve post-processing reporting.
- **Between objects** – where transactions occur between objects e.g. grain trading between households and traders, the data for each object must be correctly adjusted for both sides of the transaction. For example, if a household sells grain to a trader, both will see an effect upon grain stocks and upon cash. The framework should ensure that consistent accounting occurs in the data for the two objects i.e. the decrease in grain stocks in the selling household should be equal to the increase in the trader’s grain stocks; similarly, the increase in cash in the household should match the decrease in the trader’s cash. Without such safeguards, validation of rules will be difficult.
- **Between levels of the hierarchy** – if the C.I.A.O. concept is adopted, this issue should not arise for the majority of transactions in the food system i.e. those relating to grain trading. However, other cross-level consistency issues will include the need for referencing of behaviour at one level to data relating to objects in another level. For example, crop growth within a household will depend upon ward level rainfall and (probably) household level farmer knowledge, labour availability and use of inputs. Cross-level consistency will also be necessary for accumulations of data for reporting purposes. For example, although the numbers of individuals sick or malnourished at ward level and above will not be required in the modelling of the food system (unless

the values are used to trigger food aid), the reporting of these statistics will be one of the principal user outputs and will also be used to validate the overall model (this is discussed below).

6.9 Short term factors

The behavioural rules will be applied to the data of the various objects in the hierarchy. Some of these data will remain constant for the simulated agricultural year e.g. for households, type of sanitation, whilst others will alter dynamically e.g. household food stocks. The changes in these dynamic data will occur as a result of the changes in the coefficients of the behavioural rules that relate to the impact of the short-term factors. The short-term factors are principally rainfall, disease rates and economic variables, such as G.M.B. prices of the principal staples.

6.9.1 Rainfall

The use of rainfall data herein, via simple crop growth models for each staple, provides an estimate of harvest outturn. This estimate changes as the simulation of the season progresses and is of particular importance at two periods during the year. In January- February, when the critical growing stages have passed, if rainfall has been good, farmers will have good harvest expectations and will sell any surplus grain (obviously, with bad expectations they will retain their existing stocks). In March-April, the harvest will provide replenishment of household grain stocks and may also provide grain surpluses for sale.

Although the agro-ecological zoning implies different levels of rainfall, it is clear that annual rainfall variability is significant. This temporal variability has two aspects: aggregate rainfall and the timing of rainy periods within the wet season. There is also spatial variability of rainfall, evidenced at coarse scale by the existence of the different agro-ecological zones. This coarse variability is the aggregate of underlying variability as between the different wards and also has the two aspects as above i.e. aggregate amount and rainy season 'profile'.

In order to run simulations of the food system, the implemented models must be provided with rainfall showing the temporal and spatial variability appropriate for the study district. For the Buhera District, historic satellite data are available in ten-day intervals for areas of 50 sq. km.. Rainfall data are also available from meteorological stations, although the network around Buhera is sparse. These historic data were used to create rainfall scenarios, invoking particular conditions appropriate to the simulation desired e.g. ‘average rains’, ‘drought’, or ‘severe drought’. The method of derivation of these scenarios is described in more detail in the next chapter.

6.9.2 Disease rates

In the second stage of the development of the ‘Health/Nutrition’ component of the systems dynamic framework (see section 5.8), disease rates were applied to community level models using a combination of background rates (derived from district level morbidity and mortality statistics) and local factors (aggregate water access, sanitation etc.). This approach was substantially retained for the second framework.

In a similar method to that used for the rainfall data, disease data derived from historic district level morbidity statistics provide scenarios for the major disease groups, for children and for adults, to enable users to invoke various incidence levels such as ‘epidemic’, ‘average’ and ‘below average’. These background rates are then modulated by household level conditions (accessed by the behavioural rule from the data about each household) to provide disease rates to apply to each cohort within a household, within each dekad.

6.9.3 Economic variables

As Vaze (1999) has shown, the most important economic variables for the simulation of the food system, over one agricultural year, are the reference prices of the principal staples: maize, sorghum, millet, rapoko and groundnuts set by the G.M.B. at the start of each season. These prices, both buying and selling, are fixed pan-seasonally and pan-territorially. They are always available to households and traders, providing that the G.M.B. is not grossly overstocked (and not buying) or suffering severe shortages

due to widespread harvest failure (and not selling). With the implementation of the C.I.A.O. concept as part of the framework, the local (i.e. within district) price movements can be modelled without direct reference to separate files of short term changes, provided that the G.M.B. prices are known and set at the start of the simulation. Note, however, that rainfall data by ward by timestep will be required to determine the influence upon a household's expectations of the current year's harvest and as such the household's assessment of its surplus/deficit position and hence its decision to trade. (For applications in other countries or if the G.M.B. pricing policy becomes more market oriented, such short term price files would be required.) Additionally, Vaze shows that price in any ward is also dependent upon (i) the transfer cost d_i between the nearest G.M.B. depot and the ward; (ii) the transfer costs m_{ij} between surplus/deficit ward pairs; and (iii) the interest rate. The level of interest rate will determine the extent to which traders can engage in intertemporal arbitrage by storing crops purchased in periods of surplus and low prices to meet demand later at higher prices. The interest rate is assumed to be the opportunity cost for the trader of having his funds tied up in grain stocks. With high levels of interest rates, intertemporal arbitrage will be unattractive unless there is rapid grain price inflation, which is unlikely in the case of Zimbabwe because of the way in which the GMB sets pan seasonal prices.

Retail price inflation remains high in many sub-Saharan countries and in Zimbabwe interest rates are currently (as at 2000) around 60% per annum. At lower levels, the effects over an agricultural year would be small relative to the overall sensitivity of any implemented model. However, at the level shown, there will be a material effect upon farmers' and traders' attitudes to storage costs of grain, with the fixed G.M.B. prices favouring early season sales and late purchases. These issues should be addressed by the individuals responsible for the detailed development of the grain pricing functions within the rules relating to grain trading.

Other important economic variables are the urban unskilled wage rate (for determining the income of migrant workers), urban living costs (for determining the expenditure of migrant workers and hence the net cash available as remittances), state

pensions, school fees, health fees, bus fares etc.. All of these can be set at the outset of the simulation, with a monthly increase for inflation, where necessary.

6.10 Output, calibration and validation

Storing the data separately from the behavioural rules, with the intermediate values provided from every time step, provides the potential for comprehensive tabular and graphical outputs from the simulation. Furthermore, by incorporating spatial references in the objects, at least to ward level, will enable links to a G.I.S. to be provided. The output module should provide users with various reports about the simulation, using G.I.S. techniques as the central provision of output data. It will be necessary to evaluate with users which reporting methods are preferred. There are various choices of method: cartographic / graphical display of aggregated results, descriptive statistics or graphical display of data sub-sample. Users may prefer to see some averaged measure of multiple sample runs with the same scenarios started with different random seeds.

Oakshott suggests three stages of validation for any simulation model (see section 5.3 for more details): face validity, assumption / parameter testing and statistical comparison. The first two of these can be undertaken as part of the testing of each of the sets of rules implemented by users as sub-models and the various output formats will facilitate both.

However, the third stage validation will present problems. Ideally multiple simulation runs would provide data upon which detailed statistical analyses can be performed and comparison made with independently collected data. Whilst this may be possible for the individual sub-models, validation of the overall implementation by examining predicted levels of malnutrition is difficult due to the absence of independent, comprehensive data covering the whole population under study. In Zimbabwe, standard government information is limited to child malnutrition statistics for under 5's who have attended growth monitoring clinics and morbidity statistics (containing some nutrition data) based on patients attending health clinics.

The bias in these data presents problems for their use in calibrating models such as is developed herein. To use such data for calibration and validation, an attendance model has been investigated by a colleague from the collaborative research project (see Wright, 1998) that assesses the likelihood of children taking part in the health centre growth monitoring programme. The probability of a given child being measured at a given facility is estimated based on the type of health facility, the characteristics of the child's household, the distance between the two, and the proximity of other equivalent types of facility. This relationship is estimated using logistic regression on field survey data and then applied to all of the households in the simulated population. The number of children attending each health facility can therefore be estimated, giving figures directly comparable to the aggregated health centre statistics. Incorporation of a module to simulate healthcare uptake means that aggregated model results can be validated for the youngest population cohort. Conditions in past years can be replicated within the model and output compared to historical records for different health centres across the district. Wright's results however are not conclusive as to the efficacy of this approach and care will be needed in its application to the validation of the implemented models. If Wright's method cannot be successfully applied, validation of the models overall will remain problematic and restricted to the separate validation of the individual researchers' sub-models.

6.11 Remarks

At this point, the fundamental features of the second framework design were becoming clear: (1) a hierarchical representation; (2) special treatment of grain trading, perhaps using the C.I.A.O. concept; (3) rule-based models initiating discrete events and transactions rather than flows; (4) separation of data from models (5) special 'data generators' for rainfall and disease. Two issues remained to be considered.

The first concerned the setting up of the initial file of objects and related data on which the simulations were to be performed. It had originally been expected that detailed census data would be obtained with which to 'populate' the simulation. This was not forthcoming and methods had to be devised to create an artificial population

for the study district of Buhera, from the household survey data and summary census statistics. This is fully described in the next chapter.

With systems dynamic methodology having been discarded, the second issue concerned the choice of modelling approach. The recursive nature of the C.I.A.O. concept was entirely compatible with 'object oriented programming', the second approach on the shortlist that had been identified during the literature review (see the 'Remarks' section in chapter 2). From discussions with computer programmers, it was clear that it would have been feasible to develop a base C.I.A.O. object class in any of the main object oriented programming languages, complete with the procedures for trading and pricing. This would have allowed the modelling framework to be constructed as a series of C.I.A.O. objects for household, ward, zone and district each of which would have been derived from the base C.I.A.O. object class. This series of objects could then have been modified to take account of all the other behaviours (additional to grain trading). This would have required each colleague in the collaborative research project to prepare detailed specifications for each part for which he/she was an expert as guidance for dedicated computer programmers. In effect, the project would have been taking on a comprehensive development of an object oriented computer program.

Although this approach was attractive, particularly as there was strong similarity with other researchers' work being carried out on agent based modelling, it was felt that such a scale of computer programming development would be excessive for a collaborative research project, staffed by non-computing specialists.

With some reluctance therefore, it was decided to implement the ideas in this chapter using the third choice of modelling approach, an expert systems simulation. The benefit of this was primarily that the individual behavioural rules could be encoded directly by the 'experts' within the project team, rather than having to rely on computer programmers. It was also felt that the longer term use of an O.O.P. would not be excluded by this choice and the expert system simulation could incorporate some of the C.I.A.O. ideas, albeit within rather a limited scope.

In summary, these further considerations about the design of the modelling framework have now achieved the third objective set in chapter 1, viz.: *'To develop methods for inter-relating the analyses, within a modelling framework, to support the coherent representation of the processes underlying the food system'*.

They have also prepared the basis to fulfill the fourth and fifth objectives, namely: *'To provide a modelling framework that will enable users to represent household and community resources and the short-term external factors'* and *'To include, within the modelling framework, suitable methods of providing output data, about changes in nutritional status, which are sufficient for comparison with independently derived data to confirm or otherwise the coherent representation of the processes.'*

7 Framework II – an expert system simulation

7.1 Purpose

This penultimate chapter describes the second design of the modelling framework, which is structured as an expert systems simulation. The framework enables users to specify sets of rules to describe behaviour occurring in response to short term factors and to apply these to a hierarchy of households, wards and agro-ecological zones in order to simulate the changes therein. The overall structure of the framework and five of the main components – the hierarchical population database, the rule base, the generation of short term factors, the simulation engine and the rule editor – are described. Particular attention is given to how the design interrelates the rules with the population database to ensure spatial and temporal consistency in processing. The extent to which the C.I.A.O. concept is implemented within this framework is discussed. As part of the framework, the author developed with others a method for extrapolating the population database from a combination of secondary data and the household survey. This is described in detail. The author was involved in the development of a method for simulating localised rainfall from meteorological station data. This is summarised. Due to delays in entering rules, the framework has not yet been implemented as a working model. As a result, the comments on output, calibration and validation in the previous chapter have not yet been translated into detailed design specifications and further reporting of these matters in this chapter has been omitted.

7.2 Overall structure

The structure of the simulation model is shown in Figure 7.1 overleaf. The core of the framework is shown in bold and comprises a *simulation engine*, which applies stochastic and deterministic behavioural rules from a *rule base*, to the *population database*, over a number of time steps t_1 through t_{36} . For each time step, various *short-term factors*, particularly changes in rainfall and disease rates, are applied to each ward and the resultant response of households to these changes is propagated to the higher-level community structures of wards, agro-ecological zones and district.

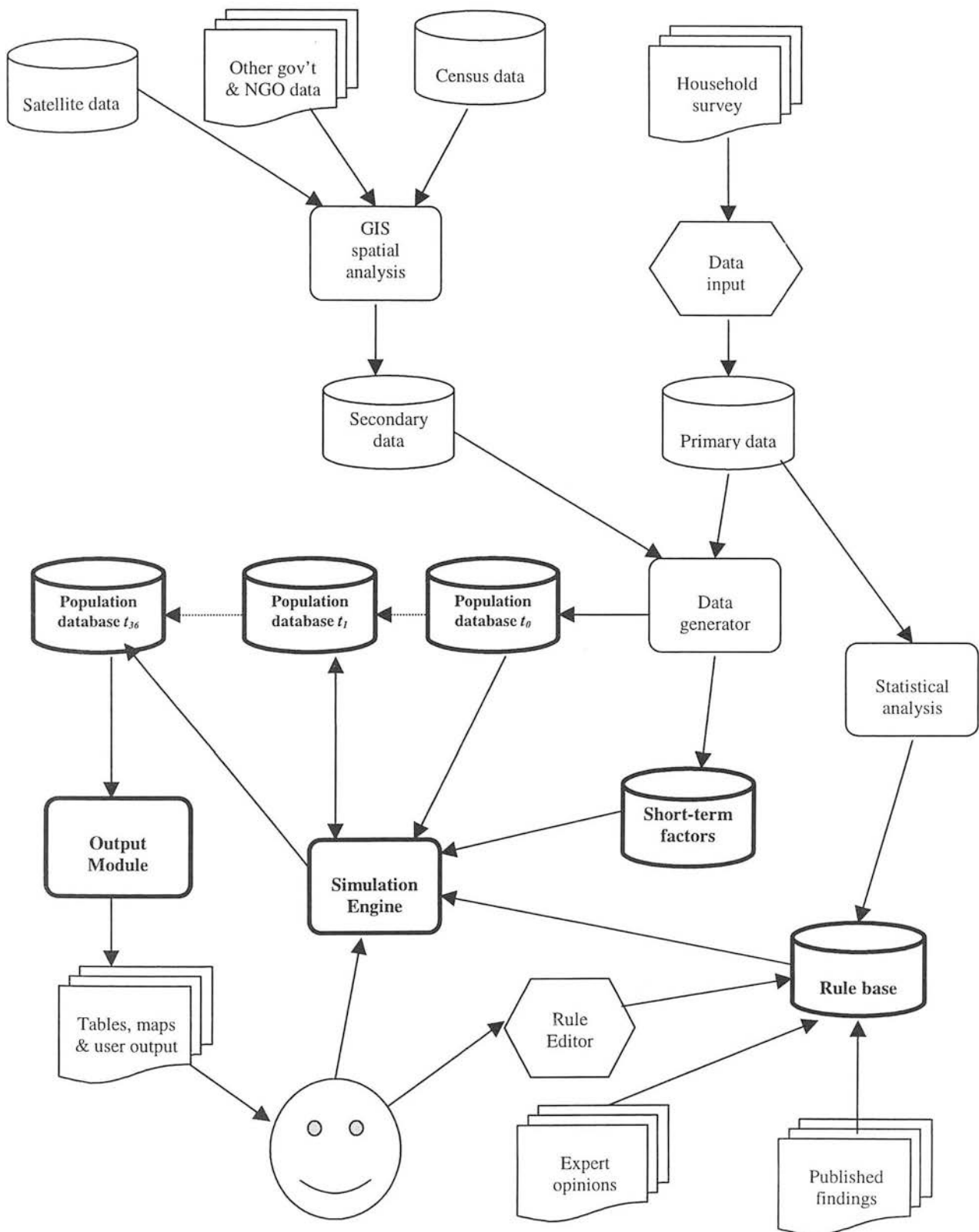


Figure 7.1 Outline of second modelling framework and information flows (Source: Gundry et al. 1998)

Each time step t_n , represents a ten day period (dekad), chosen because this is the standard unit for rainfall data and allows appropriate scaling of crop growth and illness/recovery. At time t_{36} , the end of the agricultural season, the *output module* provides a series of tables, maps and statistical data to the user.

The framework uses a modular approach, based in part on existing software packages. A relational database is used to hold details of households, wards and agro-ecological zones within the district (*population database*) and the rules (*rule base*). A Geographical Information System (G.I.S.) is used for cartographic reporting within the *output module*. The other two core components (*simulation engine* and *short term factors*) are purpose written, as is the *rule editor*, which is used to input, edit, manage and compile the rules within the *rule base*. The diagram in Figure 7.1 also encompasses the associated information flows. Five subsidiary modules are associated with the core:

- Pre-processing of secondary data;
- Analyses of household survey data;
- Data generation of the population database;
- Data generation of the short-term factors;
- User input/modification to the rule base.

The pre-processed secondary data and the household survey data both provide input to the data generator, which is used to create the population database for the simulation. Secondary data are also used to create files of rainfall and disease data, which as short term factors, are the principal vectors of temporal and spatial changes. The household survey data are also analysed statistically and combined with expert opinions and published research findings to form the behavioural rules input by users to the rule base.

An important feature of this design is the separation of the *data* from the *experiment* in the simulation framework. The population database holds the *data* and the other components of the framework (the rule base, the short term factors, the simulation

engine and the output module) perform the *experiment* and report its results. It is therefore appropriate to describe the population database initially.

7.3 Population database

7.3.1 Hierarchical structure

The population database is an extrapolated sample, representative of the population of the study district of Buhera. It includes 3,834 households, being ten percent of the households in the 34 rural wards of Buhera District (a further two urban wards, with 613 households in aggregate, are excluded from the simulation). The choice of a 10% extrapolated sample was somewhat arbitrary, balancing the processing requirements of a larger sample against the need for sufficient households to be present in the simulation to give effect to the inter household grain trading mechanism. The method used to extrapolate the data for each household is described in section 7.6.2 below.

The population database has a hierarchical structure with one record for each element in the four levels: district, agro-ecological zone, ward and household. The total number of records in the population database is therefore:

Level of hierarchy	Number of records
District	1
Agro-ecological zone	3
Ward	34
Household	3,834
Total	3,872

Table 7.1 Number of records in each level of the hierarchy in the population database

(N.B. Following the 1992 Census, boundaries were re-drawn and some amalgamation of wards occurred, reducing the number from 34 (plus 2 urban) to 30 (plus 2 urban) per the household survey.)

The households are referenced by district, agro-ecological zone and ward. Each household has one static table of data and six dynamic data tables. Each element in

the levels of the hierarchy above household also has a static data table and three dynamic data tables. The dynamic tables in every level of the hierarchy are also referenced by time period, being the dekads 0 through 36. The structure of the hierarchy within the population database, the data tables for each element and the key (referencing) fields for each table are shown in Figure 7.2 overleaf. These are followed by Figures 7.3 through 7.8 showing the full tables for each element in each level of the hierarchy.

Taking each level of the hierarchy in turn, the data tables for each element are described below.

7.3.2 Household

See Figures 7.3 through 7.5. Each household has a ‘*Static*’ data table, which stores information about socio-economic and agricultural characteristics. There are also six dynamic data tables: ‘*People*’, ‘*Indicators*’, ‘*Crops*’, ‘*Cash*’, ‘*Food*’ and ‘*Livestock*’. A brief description and purpose of each of these is as follows:

◆ **tblHouseholdStatic**

This table includes boolean and categorical variables to characterise gender, age and education of the household head and education level of first wife (i.e. allowing for a polygamous household), religious sect membership and polygamy, some or all of which are known to influence agricultural performance, illness and recovery. It also includes various housing characteristics: sanitation, water and house type and size, each of which is known to influence illness. Descriptors of agricultural variables: inputs, equipment and cropping patterns are also included to allow agricultural performance to be modelled. Variables about sundry food sources and dietary quality are also stored. The last two fields in the static table identify whether or not the household is in receipt of off farm income and/or remittances.

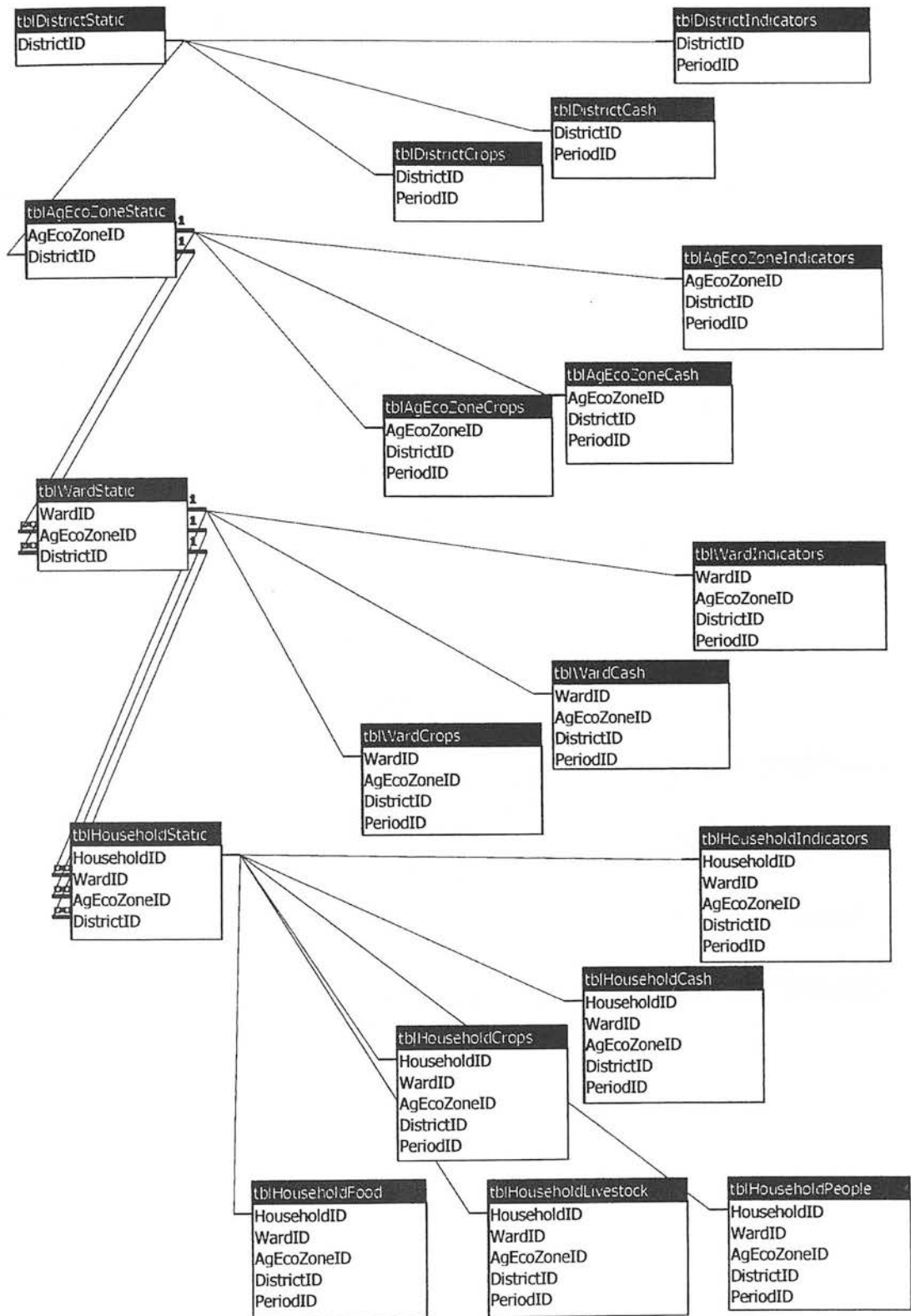


Figure 7.2 Population database structure of district, agro-ecological zone, ward and household and data tables for each element therein.

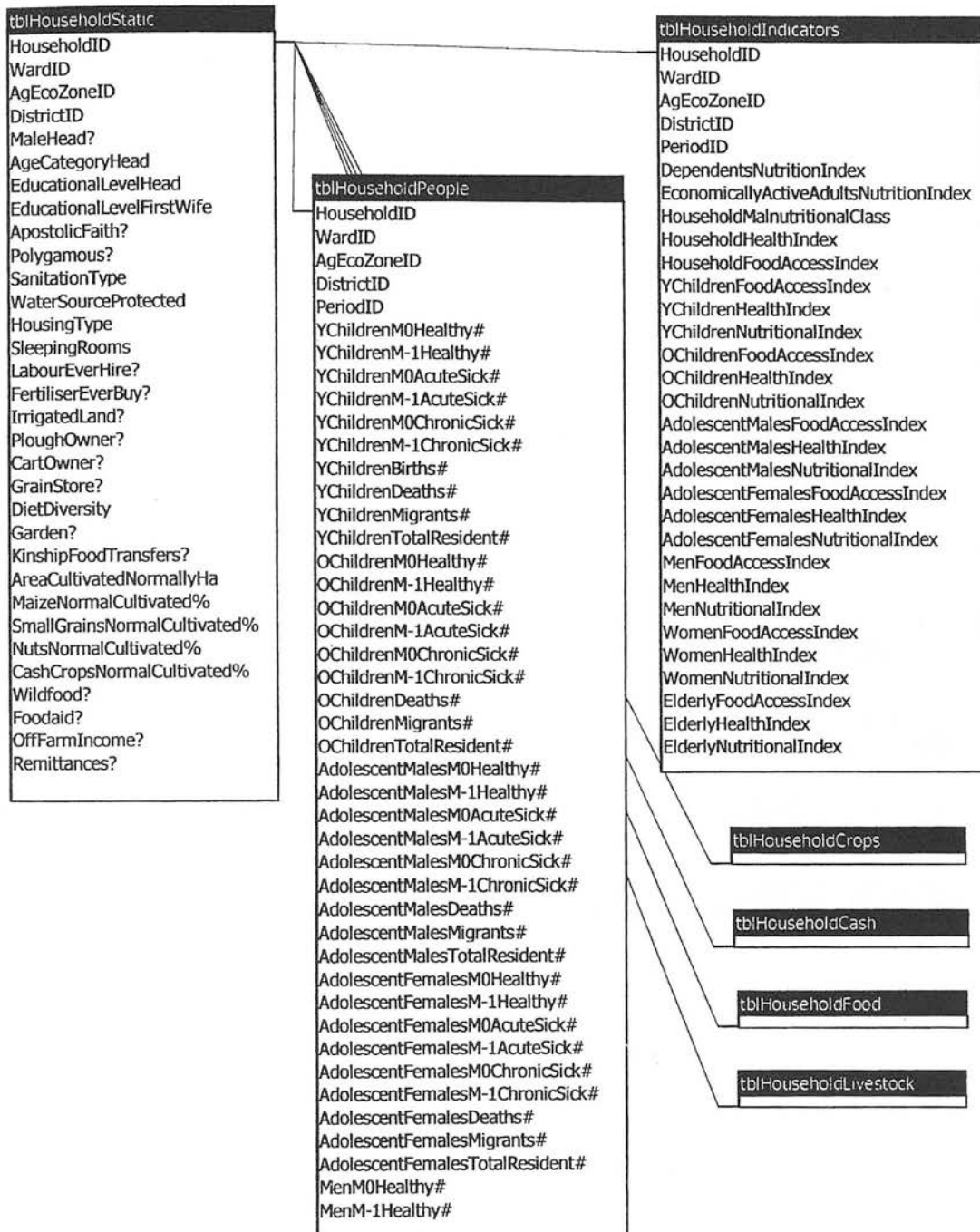


Figure 7.3 Data tables for each household, with field listings for 'Static', 'People' and 'Indicators'.

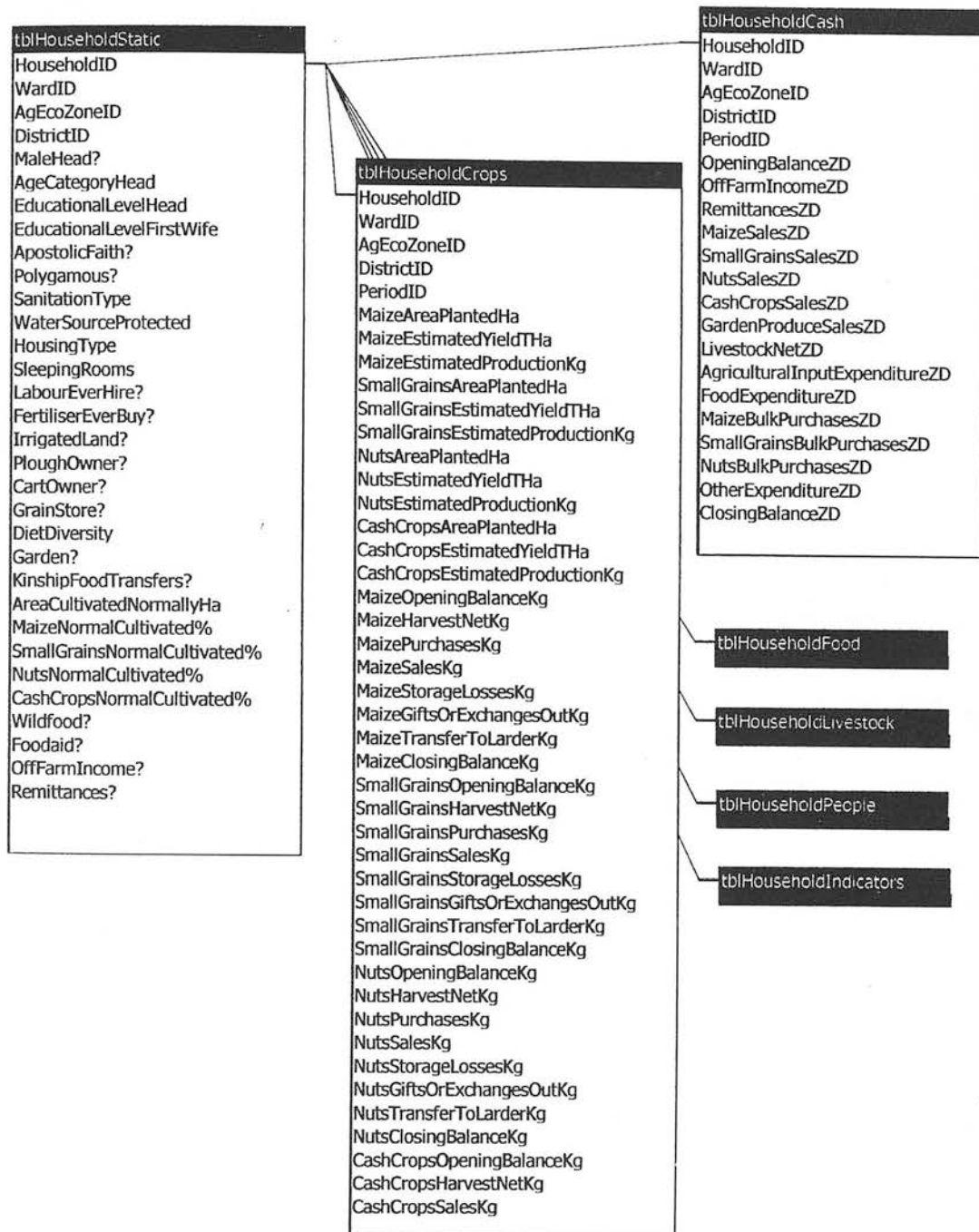


Figure 7.4 Data tables for each household, with field listings for 'Static', 'Crops' and 'Cash'.

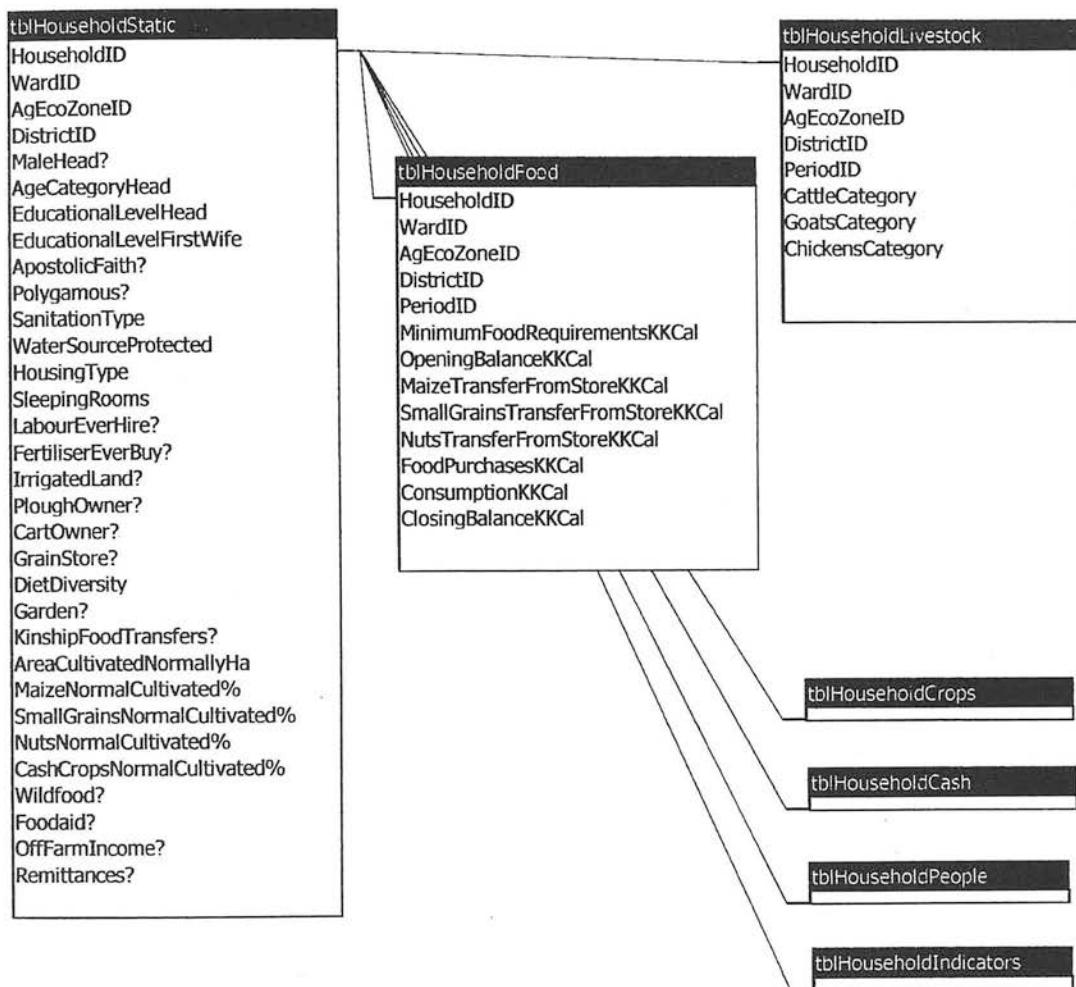


Figure 7.5 Data tables for each household, with field listings for 'Static', 'Food' and 'Livestock'.

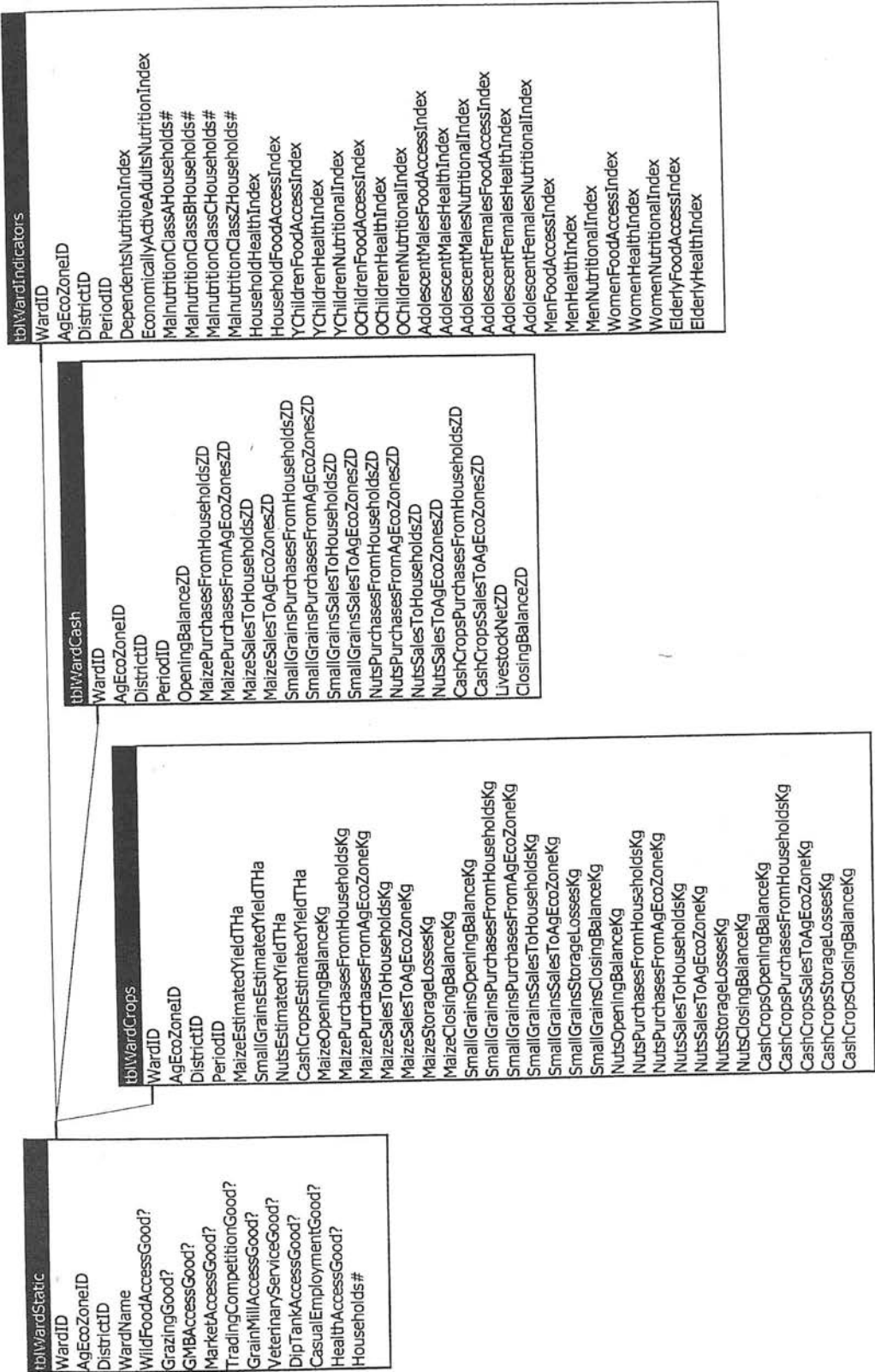


Figure 7.6 Data tables 'Static', 'People' and 'Indicators', for each ward, with field listings.

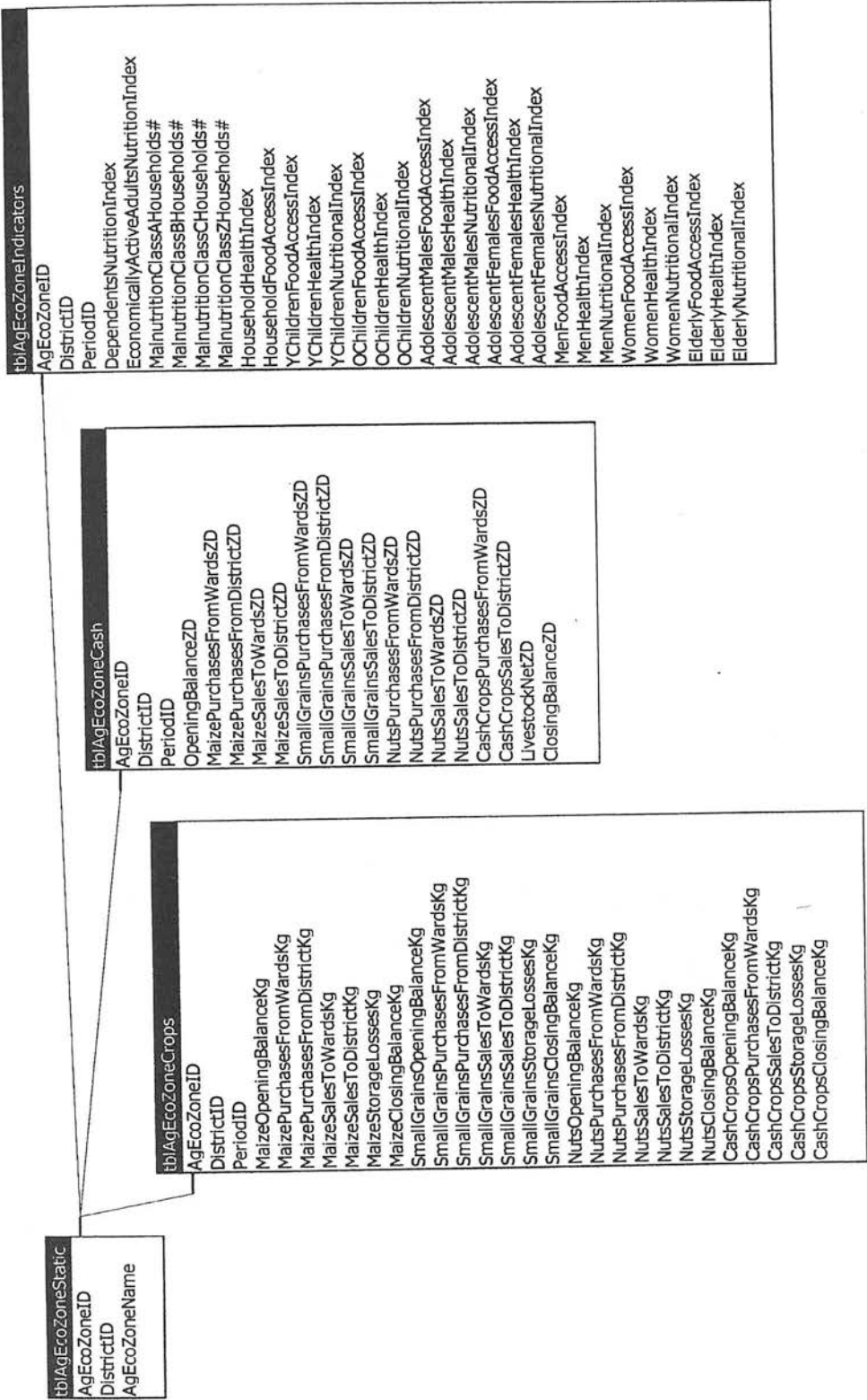


Figure 7.7 Data tables 'Static', 'People' and 'Indicators', for each agro-ecological zone, with field listings

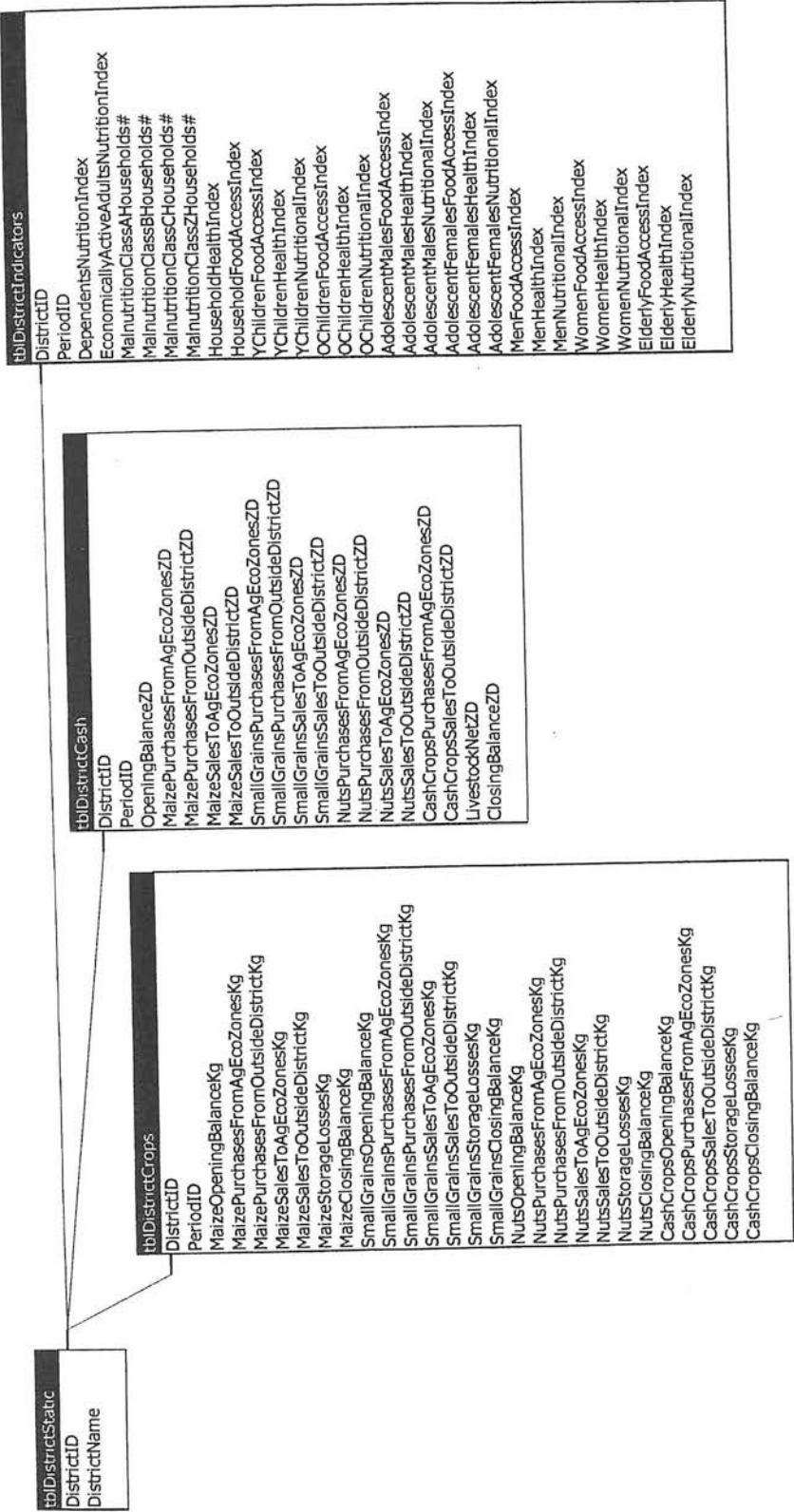


Figure 7.8 Data tables 'Static', 'People' and 'Indicators', for the district, with field listings.

◆ **tblHouseholdPeople**

(N.B. Due to the restrictions in the database software, the diagram in Figure 7.3 omits seven of the nine fields for 'Men' cohort and all nine fields for each of 'Women' and 'Elderly' cohorts. These fields follow the format of those for the other cohorts.)

This table records at each time step the numbers of individuals within each health / nutrition category, for each of seven age cohorts. It is similar to the 'four-box' concept described in section 5.6 'Health / nutrition – stage 1', but with sickness split into acute and chronic, to give a 'six-box' format. Those individuals classified in chronic sickness categories as part of the extrapolation of the population database at time t_0 can die in future time steps, but otherwise will remain chronically sick for the duration of the simulation period of one year. No new chronically sick cases will be created. This is to reflect the significant incidence of chronic illness amongst adults and elderly. There are two levels of malnutrition for the three health categories and these are labelled M0 and M-1. Both reflect levels of protein-energy malnutrition (cf. specific micronutrient malnutrition) and the latter category, M-1, comprises those who are malnourished or severely malnourished, with the remainder of the cohort being classified as M0. Thus M0 will include those mildly malnourished, adequately nourished and over-nourished or obese. This is justified as it is essentially the purpose of the simulation to forecast the changes in numbers of M-1 individuals and not to provide a comprehensive view of nutritional wellbeing amongst the population of the district.

In addition to the six categories of health / nutrition, a running total of births (young children only), deaths, migrants and residents will be maintained for each cohort. The seven cohorts are:

- (i) Young Children (under 5 years old);
- (ii) Older Children (5 years and older, but under 10 years old);
- (iii) Adolescent Males (10 years and older, but under 18 years);
- (iv) Adolescent Females (10 years and older, but under 18 years);
- (v) Men (18 years and older, but under 50 years);

- (vi) Women (18 years and older, but under 50 years) and
- (vii) Elderly (50 years and older).

These cohorts have been chosen in conjunction with the nutritionists in the collaborative research project to fulfil several purposes. Firstly, the cohort boundaries should accord as closely as possible with those in use for nutritional, morbidity and mortality statistics in Zimbabwe and internationally. This will enable cohort sickness rates to be obtained for use as short term factors (see section 7.6.1 below) and will enable validation of the implemented models against independent data. For the elderly cohort, the alternatives were either 50 or 55, with life expectancy in the Manicaland Province of Zimbabwe in 1990 being 57 (Government of Zimbabwe, 1994). The former was chosen as it is the point at which the economic 'activity rate' (the ratio of economically active persons to all persons aged 15 years and above) begins to fall for males and females (*ibid.*). Secondly, within each cohort, the basis of measurement of malnutrition should be the same. Thus, in the two children's cohorts, the malnourished classification M-1 will apply to those having a Weight-for-Height Z-score of -2 or below (i.e. having a weight for a given height which is at least two standard deviations below the international reference mean). Children less malnourished than this will be classified as M0.

For adolescents of either sex, malnutrition will be measured by Body Mass Index (B.M.I.) and those with a B.M.I. lower than those shown in Table 7.2 below will be classified as M-1, otherwise M0.

Age class	Males	Females
10-11	13.37	13.05
11-12	13.40	13.23
12-13	13.60	13.54
13-14	13.90	14.00
14-15	14.32	14.56
15-16	14.92	15.28
16-17	15.63	16.02
17-18	16.30	16.75

Table 7.2 B.M.I. cut-off points used to define malnutrition classification in age cohorts 'Adolescent Males' and 'Adolescent Females'. (Source: d'Amato, 1999)

For malnourished adults (i.e. the age cohorts 'Men' and 'Women') and 'Elderly', the usual international standard cut-off of B.M.I. of 18.5 or lower will apply. Note that these cut-off levels for each cohort are intended to provide a physiological reference point for output from the simulation, but they should not be taken to imply that the population database will 'track' individuals by anthropometric values. Members of cohorts will be reclassified between M0 and M-1 through the operation of the rules relating to intra-household food allocations.

The third justification for the age cohort choice is the broadly homogeneous behaviour that can be attributed to these cohorts for a rural community in Zimbabwe. Young children remain at home and are in need of maternal care. Older children may attend school, with the associated energy usage in walking thereto and the likely reduction in meals from three times to twice daily. Adolescents are likely to contribute partially to the household economy, either by working on the family land, earning off farm income or by domestic duties and providing care assistance. Adults are full contributors to the household, through agricultural activity, off farm income earning (including migration and remittance) and domestic duties and care of children and other dependents. The cohort for women also broadly covers the child-bearing age and so allows the pregnancy and births to be simulated. The elderly are classified

as dependents and are not regarded as contributing to the household economically. (It is recognised that this generalisation will require amendment in subsequent work to take account of pension income and assistance with child care provided by the elderly.)

◆ **tblHouseholdIndicators**

This table comprises three indices of food access, health and nutrition for each of the seven age cohorts and for the household in aggregate, with the addition of two indices to measure the nutritional status of dependents (young children, older children and elderly) and economically active adults (male adolescents, female adolescents, men and women). The food access indices are, in all cases, derived from the calorific value of the quantity of food allocated to the cohort compared to the calorific requirements for the cohort each period, taking account of changes in requirements brought about by sickness etc. The health indices are, in all cases, the disease rate for each cohort in each period relative to the background rate (i.e. as provided by the file of short term factors) for the cohort, taking account of household influencing factors and sickness amongst siblings. The nutritional indices for the seven age cohorts and the 'Dependents' and 'Economically Active Adults' aggregate cohorts are the proportions of M-1 individuals within the cohorts.

For the nutritional index of the household as a whole, it was recognised that a classification scheme based on a simple proportion of the aggregate household members would mask the possible different nutritional outcomes for children and elderly arising from the greater impacts of health amongst those cohorts.

Accordingly, it was decided to classify households in four categories, as follows:

- A – Adults** and Adolescents malnourished, other cohorts not malnourished;
- B – Both** Adults (and/or Adolescents) and Children (and/or Elderly) malnourished;
- C – Children** (and/or Elderly) malnourished, other cohorts not malnourished;
- Z – Zero** malnourished cohorts.

This ABCZ categorisation is not an ordered scheme, but is designed to offer insight into the causes of malnutrition when used to provide summary statistics for a

community, as it allows certain inferences to be made that would not be possible with a simple proportionate household index. For Category A households, the malnourishment amongst adults and/or adolescents only would indicate that either food shortages are causing intra-household food rationing in favour of dependents or that debilitating adult diseases (e.g. AIDS) are reducing nutritional status, despite conditions of adequate food access. Category A households will also have a potential income loss as the work capacities of the economically active adults will be compromised. For Category B households, malnutrition amongst both adults and dependents implies that household food access is inadequate (or possibly that there has been an outbreak of debilitating disease across all cohorts). In Category B households there will also be a potential income loss as the work capacities of the economically active adults will be compromised. In Category C households, the malnourishment amongst children and/or elderly only would indicate three possible causes: that food shortages are causing intra-household food rationing in favour of adults; or that children are missing meals (involuntary intra-household rationing); or that debilitating child (or elderly) diseases (e.g. diarrhoea) are reducing nutritional status, despite conditions of adequate food access. Category Z households would be regarded as free from problems of reduced food access at household or cohort level and also free from debilitating diseases. The advantage of such a scheme is that emergency assistance to the affected communities can be more accurately targeted and the appropriate mix of food and medicines distributed.

◆ **tblHouseholdCrops**

(N.B. Due to the restrictions in the database software, the diagram in Figure 7.4 omits the following fields: CashCropsStorageLossesKg; CashCropsClosingBalanceKg; MaizeYieldPerformance%; SmallGrainsYieldPerformance%; NutsYieldPerformance%; CashCropsYieldPerformance%; HarvestDate.)

For each of four modelled crops ('Maize', generic 'Small Grains', ground 'Nuts' and generic 'Cash Crops'), this table records, at each time step, the current season's growth and the quantities held in storage, together with the inflows and outflows from the store.

For each of the current season's growing crops, the table records the planted area in hectares (which may change in the event of replanting due to poor early rains), the estimated yield in tonnes/hectare and thus the estimated production in kilograms, being the product of the first two fields, multiplied by 1,000. Note that each of the '...EstimatedYieldTHa' fields is calculated by multiplying each of the fields '...YieldPerformance%' by the ward level fields '...EstimatedYieldTHa' (in 'tblWardCrops'). This is because the crop growth model is applied to rainfall estimates generated at ward level, to give average estimated yields. Each household within each ward will then have harvest expectations based on its relative performance compared to the ward average. This relative performance is based on historic yields, but may vary dynamically (e.g. if inputs have not been purchased in the current year). A single harvest date (for maize, from which other crops' harvest dates can be inferred) is also recorded in this table and whilst usually staying constant for the season, will vary if a second planting occurs following the failure of the first planting.

For each stored crop, for each time step, the table records the opening balance quantity, the inflows, outflows and thus the closing balance. Clearly the closing balance in period t becomes the opening balance in period $t+1$. Inflows of food crops comprise the net harvest and purchases. Outflows comprise sales, storage losses, gifts/exchanges made and, most importantly, the quantities transferred to the 'larder' for household consumption. For cash crops, purchases are omitted from inflows and gifts/exchanges and transfers to larder are omitted from outflows. All fields for stored crops are held in units of kilograms.

◆ **tblHouseholdCash**

Analogously to the stored crop fields, cash is recorded in each time step by a combination of opening / closing balances and inflows / outflows, in units of Zimbabwean dollars, the local currency. Individual inflows and outflows are recorded separately in each time step to assist with validation of the implemented models. (Note that 'LivestockNet' is a combined transaction of livestock purchases, livestock sales and livestock input expenditure because the household survey data would not support the separate treatment.)

◆ **tblHouseholdFood**

This table is effectively a record of the ‘larder’ for the household, plus a single field to record the food requirements at each time step. The method of maintaining the ‘larder’ records is again similar to that used for stored crops, with opening / closing balances and inflows / outflows, but with outflows restricted to consumption.

◆ **tblHouseholdLivestock**

This version of the framework includes simplified livestock recording and modelling. The quantity owned of each class of livestock (cattle, goats, chickens) is recorded as a category, as follows: 0=none; 1=1-4 animals; 2=5-9 animals; 3=10+ animals. The use of these categories is especially useful for cattle where for example, 1-4 animals gives the farmer access to draught power with the consequent effect upon labour requirements and/or crop area planted. Net livestock income is then derived for these quantities from the analysis of the household survey data.

7.3.3 Ward

See Figure 7.6. Each ward has a ‘*Static*’ data table, which stores information about the local socio-economic, environmental and agricultural conditions. There are three dynamic data tables: ‘*Crops*’, ‘*Cash*’ and ‘*Indicators*’. A brief description and purpose of each of these is as follows:

◆ **tblWardStatic**

This table comprises boolean variables to characterise the quality within the ward of wild food, livestock grazing, access to markets (including proximity to G.M.B. depot, other markets, competition, millers), access to veterinary and health services.

‘Quality’ is relative to the median for all wards within the district, as determined by analyses of secondary data. It is envisaged that the detailed sub-models will use these variables to modulate household behaviour, based on the qualitative state of ward resources/infrastructure, possibly via the household variables e.g.

'if tbl.WardStatic.WildFoodAccessGood? = 'Yes'

then tbl.HouseStatic.WildFood? = 'Yes''

so allowing the household to receive wild food when a shortfall in own produced or purchased food occurs (see section 7.4.1 Household rule base – [10] Wild food and food aid). The table also holds a check balance of the number of households within the quasi-sample being simulated for each ward.

◆ **tblWardCrops**

The records for crops at ward level include fields for the estimated average yields, resulting from application of the crop growth model to the generated rainfall for the ward, for each time step.

Also included are 'trading' records for the four crops, showing opening / closing balances and inflows / outflows. The inflows / outflows are effectively a reduced implementation of the C.I.A.O. concept, described in the previous chapter. Each ward record will show the amounts transacted by the 'central trader' with the constituent households of the ward and with the agro-ecological zone of which the ward is a member. For of each of the three food crops (maize, small grains and nuts), the inflows will comprise purchases from households and from the agro-ecological zone, whereas the outflows will comprise sales to those two levels plus storage losses. For cash crops, trades will only be in one direction i.e. inflows will comprise purchases from households and outflows will comprise sales to agro-ecological zone plus storage losses.

◆ **tblWardCash**

The cash records for the ward are part of the C.I.A.O. implementation referred to above and enable the trading between levels: household / ward / agro-ecological zone to be accounted for as to both the traded goods (i.e. the crops) and the consideration (i.e. the cash) at each level. This ensures that the necessarily rigorous double-entry bookkeeping can be maintained throughout the simulation and that the trading model can be validated more easily.

The cash table at ward level also includes the aggregate livestock net value for the constituent households, allowing a similar financial control over livestock trading to that in place for the crop trades.

◆ **tblWardIndicators**

The table of ward indicators is simply a summary function of the indicators stored for each constituent household. For the various indices, the ward field is the mean value of the constituent households. For the household malnutrition classifications of A,B,C and Z, the ward indicators are the total number of households in each classification in the ward.

These indicators enable rapid summary reporting of the key indicators and also assist with the validation of implemented models by providing a clear audit trail through the hierarchical structure.

7.3.4 Agro-ecological zone

See Figure 7.7. Each agro-ecological zone has a '*Static*' data table. There are three dynamic data tables: '*Crops*', '*Cash*' and '*Indicators*'. A brief description and purpose of each of these is as follows:

◆ **tblAgEcoZoneStatic**

The agro-ecological zone static table in this version of the framework is empty, other than for an identifying name. In subsequent versions, it will be available to store information about the zone level socio-economic, environmental and agricultural conditions. However, for simplicity of implementation, these have all been included in the ward level static table in this version.

◆ **tblAgEcoZoneCrops**

This functions in exactly the same way as the 'trading' records provided in the ward table for crops. As a simplified implementation of the C.I.A.O. concept, it records the

transactions by the ‘central trader’ at agro-ecological zone level with the constituent dummy traders in the level below (i.e. the wards) and the transactions with the dummy trader in the level above i.e. the district.

◆ **tblAgEcoZoneCash**

Analogous to the correspondence between the Crops tables at agro-ecological zone level and ward level, the Cash tables perform the same functions at the two levels i.e. they enable the trading between levels: ward / agro-ecological zone / district to be accounted for as to both the traded goods (i.e. the crops) and the consideration (i.e. the cash) at each level. Again, this rigorous control ensures that the validation of the implemented models can be more easily achieved.

◆ **tblAgEcoZoneIndicators**

This table functions in exactly the same way as the ward indicator table, providing values for the key indicators at agro-ecological zone level, as summarised from the constituent wards. It assists in reporting and model validation.

7.3.5 District

See Figure 7.8. The district has a ‘Static’ data table. There are three dynamic data tables: ‘Crops’, ‘Cash’ and ‘Indicators’. A brief description and purpose of each of these is as follows:

◆ **tblDistrictStatic**

The district static table in this version of the framework is empty, other than for an identifying name: Buhera. In subsequent versions, it will be available to store information about the district level socio-economic, environmental and agricultural conditions. However, for simplicity of implementation, these have all been included in the ward level static table in this version.

◆ **tblDistrictCrops**

This functions in exactly the same way as the ‘trading’ records provided by the ward and agro-ecological zone tables for crops. As a simplified implementation of the C.I.A.O. concept, it records the transactions by the ‘central trader’ at district level with the constituent dummy traders in the level below (i.e. the agro-ecological zones) and the transactions with the dummy trader outside the district.

◆ **tblDistrictCash**

Analogous to the correspondence between the Crops tables at district, agro-ecological zone and ward level, the Cash table performs the same functions at the three levels i.e. it enables the trading between levels: agro-ecological zone / district / outside to be accounted for as to both the traded goods (i.e. the crops) and the consideration (i.e. the cash) at each level. Again, this rigorous control ensures that the validation of the implemented models can be more easily achieved.

◆ **tblDistrictIndicators**

This table functions in exactly the same way as the agro-ecological zone and ward indicator tables, providing values for the key indicators at district level, as summarised from the constituent agro-ecological zones. It assists in reporting and model validation.

7.4 Rule base

During the course of a simulation, the population database described above records the changes occurring in each level of the hierarchy in response to changes in the short term factors: principally rainfall and illness. The nature and extent of the responses are determined by the behavioural rules, as input to the rule base by expert users via the rule editor (see section 7.6.3 below). The various rules are organised as groups that manipulate one particular aspect of behaviour for one level of the hierarchy. Each group would normally have a single expert ‘author’ responsible for the writing, testing and validation of the rules comprising the rule group.

For the household level of the hierarchy, there are thirteen rule groups. They are shown in Figure 7.9 overleaf, together with their relationship to the tables of the population database and the short term factors.

7.4.1 Household

With reference to the diagram in Figure 7.9, the following points should be noted:

- Only the principal information links are shown between rule groups, population database tables and short term factors. Other minor links have been omitted for clarity.
- In general, where rules invoke specific events e.g. the purchase of inputs, the occurrence of the event itself and any quantitative calculation derived for it will use sampling from appropriately distributed probability functions, incorporated in the rules, to produce stochastic variability. These probability functions will be determined by colleagues responsible for data analysis to support the rule derivation in each sub-model. This note is equally applicable to the rule groups for ward, agro-ecological zone and district levels of the hierarchy.

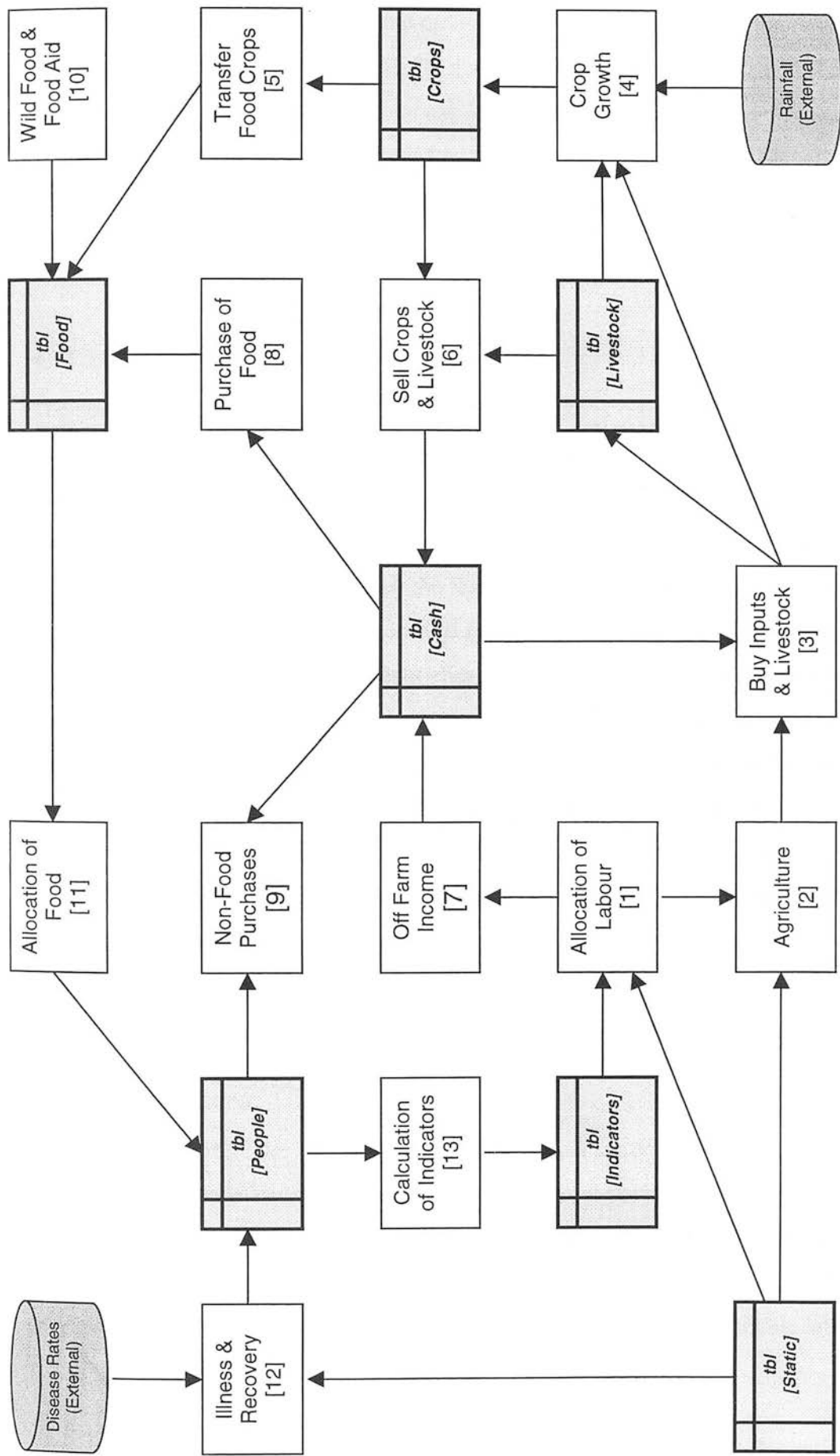


Figure 7.9 Household level rule groups, their relationship with the tables of the population database and short term factors

In the diagram in Figure 7.9., each of the thirteen rule groups for the household level of the hierarchy is numbered with the order in which it is processed. This ensures that the interrelationships with the externally generated short term factors (rainfall and disease rates) and the population database follow an appropriate cycle within each time step, prioritising use of resources towards the provision of basic sustenance. Illustrative rules, giving exemplar behaviour for the thirteen household rule groups, are described briefly below.

♦ [1] Allocation of labour

The starting point for processing within each time step is deemed to be the allocation of labour to the various income-earning tasks. For each household, the labour available in any dekad will be the number of ‘economically active adults’, taking account of their health/nutrition state, as shown by the *Indicators* table. Based on the field survey, rules will be derived by the researchers responsible for this sub-model to allocate the available labour between ‘Off farm income’ activities and ‘Agriculture’. For example, an illustrative rule might encapsulate the following: *‘If the Static table shows that the household historically has received off farm income, one unit of labour (equivalent to an adult male) is allocated to this activity and the remainder allocated to agriculture, for all dekads other than planting and harvest. This is based on the observation in the field survey that households endeavour to maintain their regular cash income in preference to agricultural tasks at all times other than the two critical periods. In the planting and harvest dekads, all labour will be allocated to agriculture.’*

♦ [2] Agriculture

From the *Static* table, the historical agricultural factors are combined with the quantity of labour allocated to determine the relative agricultural performance of the household, for translation to relative crop yields. During the ‘planting’ dekads, this rule group also determines the area of each crop planted based on historical values, as modified by G.M.B. price changes, access to draught animals and available labour at planting time.

◆ [3] Buy inputs and livestock

Subject to the *Cash* table showing available funds, the planted area and performance calculations from the previous rule group will be combined with the historical record of input use (from the *Static* table) to determine the amount to be spent on fertiliser, hiring labour etc. and the cash deducted from the available funds. Purchasing inputs will also affect the relative agricultural performance of the household. If funds are still available, a probabilistic rule determines if the household purchases livestock, with the *Livestock* table modified accordingly. (Note that this rule group is processed before any rule group producing a cash inflow and thus any funds available are effectively the cash balance from the previous time step, after all household food and non-food essential purchases have been made. This maintains the priority in the use of resources for basic sustenance.)

◆ [4] Crop growth

Although Figure 7.9 shows the generated short term factor, rainfall, interfacing directly with the crop growth rule group, this is a two stage procedure and occurs indirectly via the ward level crop growth rules. Rainfall is generated on a ward-by-ward basis and thus all households within a ward are deemed to receive the same amount. At ward level, the average crop growth for each of the four crops is calculated at each dekad, taking account of crop growth in earlier dekads to allow for plant stress arising from, for example, two dekads of drought at a critical growing point in the season. At household level, this ward average growth for each crop is then modulated by the relative yield performance for the household, as calculated in the previous rule groups. This provides an estimated yield for each crop and based on the area planted, an estimate of the expected harvest production. The *Crops* table is updated accordingly. At the harvest dekad, this rule group transfers the net production into the stored crop balance in the *Crops* table.

◆ [5] Transfer food crops

Household consumption is the preferential allocation of stored food crops. At each time step, this rule group compares the calorific value of the balance of the stored food crops in the *Crops* table with 90% of the estimated consumption requirements of

the household for the remaining dekads to harvest. If stored crops are in excess of 90% of requirements, an amount equivalent to 90% of one dekad's consumption needs is transferred from the *Crops* table to the household 'larder', as represented by the *Foods* table. The choice of crop (i.e. maize, small grains or nuts) from which to draw the transfer is arbitrary. If there is a shortfall when stored crops are compared to requirements, this rule group invokes a rationing procedure and allocates the stored crops equally for consumption in each of the dekads remaining to harvest, transferring the rationed amount from the *Crops* table to the *Food* table at each dekad. (The use of 90% of requirements recognises that even if there are adequate stocks of food crops, not all of a household's consumed calories will be derived from home produced staples and that some food purchases will be necessary. This '90%' factor can be varied by users.)

◆ [6] Sell crops and livestock

For food crops, the previous rule group compares household consumption requirements for the period to harvest with the stored crop balance. Where an excess exists, the farmer has the option to sell any surplus for cash, to neighbouring households, traders or to the G.M.B. (if nearby). However, as described previously farmers usually sell surpluses at two points during the season. Firstly, immediately post-harvest and secondly after the January growing period when harvest expectations are more certain. This behaviour is incorporated within this rule group in the two relevant dekads. In the post-harvest dekad, the calculated surplus from the previous rule group is compared to an additional full year's requirements and any excess sold (the effect of this is that the farmer takes a pessimistic view of the next harvest and assumes that he will need to feed the household for two seasons from the food crops just harvested). In the post-January dekad, the calculated surplus from the previous rule group (which will already be net of any sales made immediately post-harvest) is increased by the expected next harvest's production and compared to requirements for the additional year. Any excess is sold (the effect of this is that the farmer is now modifying his view of the next harvest and release stored crops for sale accordingly). For both period's sales, the choice of food crop from which to make the sale will be arbitrary. The sales are put into effect by updating the *Crops* table for an outflow (of

the quantity in kilograms sold) and updating the *Cash* table for an inflow (of the sales proceeds in Zimbabwe dollars).

For cash crops, no comparison with consumption requirements is necessary and the rule group operates to sell all harvest production in the dekad post-harvest. These cash crop sales are put into effect in the same way as above for food crops.

Two sundry sales are dealt with in this rule group. If the household has a garden (determined by reference to the *Static* table), the sale of garden produce is initiated and the *Cash* table is updated (in the 'GardenProduceSalesZD' field) with a standard amount of income. If the household has chickens and/or goats, livestock sales are initiated and these are assumed to be sales for slaughter and consumption. A standard amount of income for each level of livestock holding is used to update the *Cash* table, in the 'LivestockNetZD' field, with the sales proceeds in Zimbabwe dollars.

(Note that these two sundry sales are incompletely dealt with in this version of the framework, as they are not matched with purchases of food by other households. This results in garden produce and livestock being disregarded in the aggregate food expenditure and kilocalorie consumption of the ward. Although this will be amended in subsequent versions of the framework, the current situation can be justified as an approximation for two reasons. Firstly, garden produce is a relatively small contributor to calorific intake, having greater significance for micronutrient uptake. It is also of low aggregate value compared to the staples. Secondly, livestock, though of high value and high calorific content, is an infrequent purchase for consumption for most households. It will tend to be purchased by the richer households that are unlikely to be malnourished and any resultant understatement in their cash expenditure will be immaterial in the context of total expenditures.)

♦ [7] Off farm income

Off farm income comprises two elements: remittances and a composite of other non-farm sources including salaried and casual employment, craft sales and sundry trading. The rule group determines whether the household is in receipt of remittances and/or off farm income by reference to a combination of the results of the first rule

group ‘Allocation of Labour’ and the *Static* table. Standard amounts (which are subject to stochastic variability) are assumed for both types of income and the appropriate fields in the *Cash* table updated accordingly.

♦ [8] Purchase of food

With all income sources having been accounted for, the current time step’s cash inflows have been credited to the household’s *Cash* table balance. The first priority for expenditure is the purchase of food. As a minimum, the household will need to purchase 10% of its requirements to account for non-staples (see ‘[5] Transfer of food crops’ for explanation). Where rule group [5] initiated rationing or stocks of food crops are exhausted (by reference to the *Crops* table), food purchases will be calculated as the amount required to make up any shortfall and will be between 10% and 100% of requirements. In both cases, the amount of food purchased will be dependent upon sufficient cash being available as determined by reference to the *Cash* table. When purchasing occurs, the calorific value of the food is recorded as an inflow in the *Food* table and the cost recorded as an outflow in the *Cash* table.

Two points should be noted in regard to food purchases. Firstly, for simplicity in pricing and calorific values, the type of food purchased is assumed to be a staple food crop i.e. maize, small grains or nuts, although it may represent a mix of staples and non-staples (i.e. other essentials (e.g. salt, tea) and ingredients for relishes (e.g. green vegetables, karpenta)). In the *Food* table, the food purchases are not crop specific and are shown as the equivalent kilocalories bought. The purchase is further simplified by using the maize price and maize energy content to determine the amount of kilocalories received for the purchase consideration. The second point of note is the omission of bulk purchasing of staples by households. As can be seen from the *Crops* table, provision has been made to account for such trading, but in this version of the framework the procedures have not been implemented. The effect of this is that food purchasing by households is restricted to small quantities to meet the immediate consumption needs in each dekad, rather than allowing those households with adequate cash resources to buy in bulk at favourable times of the season i.e. post-harvest and January/February. As this omission will only tend to affect the richer households (i.e. those with the cash resources to buy in bulk), it is unlikely to cause

significant errors in numbers malnourished as they are unlikely to be members of such households.

♦ [9] Non-food purchases

After food purchases, this rule group determines the funds remaining from the *Cash* table to establish whether non-food purchases can be made. If such purchases are possible, they are initiated, in order of priority: healthcare costs, school fees, clothing and other goods / services. Healthcare costs are assumed to be a standard amount and reference is made to the *People* table to determine numbers to be treated. School fees are based on the number in the Older Children cohort. If funds are still available, a variable amount of cash is spent on the clothing and other goods / services. The *Cash* table is updated accordingly for the aggregate non-food purchases.

♦ [10] Wild food and food aid

At this stage of the processing cycle within the time step, some households will still have shortfalls between the balance of kilocalories per the *Food* table and the dekad's requirements. This will be after transfer of own produced crops per rule group [5] and the purchase of food per rule group [8]. These households may have access to wild foods, may be able to call on kinship food transfers from extended family members or may be registered for receipt of food aid, all of which are determined by reference to the *Static* table. If such food sources are available to the household, this rule group transfers into the *Food* table the lower of the shortfall and the aggregate of the amounts available. There is no facility in the framework for inter household support (from/to members of same family or neighbours) within the same ward. In this framework, it is assumed that transfers inwards and outwards are from/to family members living away from the study district e.g. adult children living and working in urban areas with their own households. It is a facility that should be considered for any future model development.

♦ [11] Allocation of food

The level of food access for the household has now determined the quantity of food available for consumption in the current dekad. The amount is the balance per the *Food* table in kilocalories. Two possibilities exist:

- Where the food available equates to requirements, this rule group initiates consumption by all cohorts of their aggregate needs. No members of cohorts are reclassified in the *People* table from M0 to M-1 i.e. no additional household members become malnourished. Where cohort members are already categorised in the *People* table as M-1, this rule group transfers a proportion to M0 categories i.e. existing household members who are malnourished, as defined by the cut-off measure (see the description of `tblHouseholdPeople` in section 7.3.2 ‘Household’), become ‘not malnourished’.
- Where the food available is less than requirements, this rule group initiates a rationing procedure. This can be either pro-rata, where all cohorts are allocated food in proportion to their needs or it can be biased rationing where some cohorts are preferentially allocated their requirements in full, reducing the amount available to other cohorts. The rationing strategy is determined by user input within the rules. In cohorts receiving less than their needs, a proportion of members will be reclassified in the *People* table from M0 to M-1 i.e. additional household members of rationed cohorts become malnourished. In the same cohorts, members who are already categorised in the *People* table as M-1, will not be reclassified to M0 categories i.e. household members of rationed cohorts who are malnourished, remain classified as such.

♦ [12] Illness and recovery

Using procedures similar to that described for crop growth in rule group [4], illness and recovery are two stage applications. Disease rates are external short term factors generated from a combination of infection rates observed in the household survey and the health statistics known as ‘T5 Form Data by Clinic’. These provide ward level illness rates, which are then modulated in this rule group to provide cohort illness rates for the household. The modulating factors are the various health related fields in

the *Static* table and a mechanism of ‘in-cohort sibling infection’ derived from the illness classifications, per the *People* table, for the cohort in the previous time step. These cohort illness rates are applied stochastically to the cohort members classified as healthy to determine those that are reclassified as ‘acutely sick’. As noted in the description of the *People* table in section 7.3.2, the cohort members having chronic illnesses are determined as part of the extrapolation of the population database at time t_0 and remain chronically ill for the duration of the simulation, subject only to death. No new chronically ill individuals are created as part of the simulation. Thus for the chronically ill categories in the *People* table, the illness procedure will be restricted to applying mortality rates at each time step. Similarly, for those cohort members classified as acutely sick, cohort mortality rates will determine those who die during the dekad. Recovery rates will be applied to the surviving, but acutely sick members of the cohorts. These recovery rates will also be derived in a two stage process. At ward level, the rates are based on national rates modulated by the quality of health care access in the ward (as shown in the ward *Static* table). At household level, the rates will be the ward rates, modulated further by care factors (e.g. educational level of first wife, membership of Apostolic faith) shown in the household *Static* table and by the expenditure or otherwise for health fees in rule group [9], non-food purchases. The reclassifications caused by illness, death and recovery will update the *People* table.

♦ [13] Calculation of indicators

From the updated *People* table and from the intra-household food allocations made in rule group [11], the *Indicators* table will be recalculated by this final rule group. The various indicators are described in section 7.3.2 ‘tblHouseholdIndicators’ and their calculation is straightforward computationally requiring no further description.

Note that upon completion of the calculation of indicators, the processing cycle for the household is complete. Processing will then pass to the next household within the ward, until all households therein have been processed at which point, the processing will then return to the ward itself.

7.4.2 Ward

For the ward level of the hierarchy, there are four rule groups. They are shown in Figure 7.10 below, together with their relationship to the four ward tables and to three of the household tables of the population database and also to the short term factors.

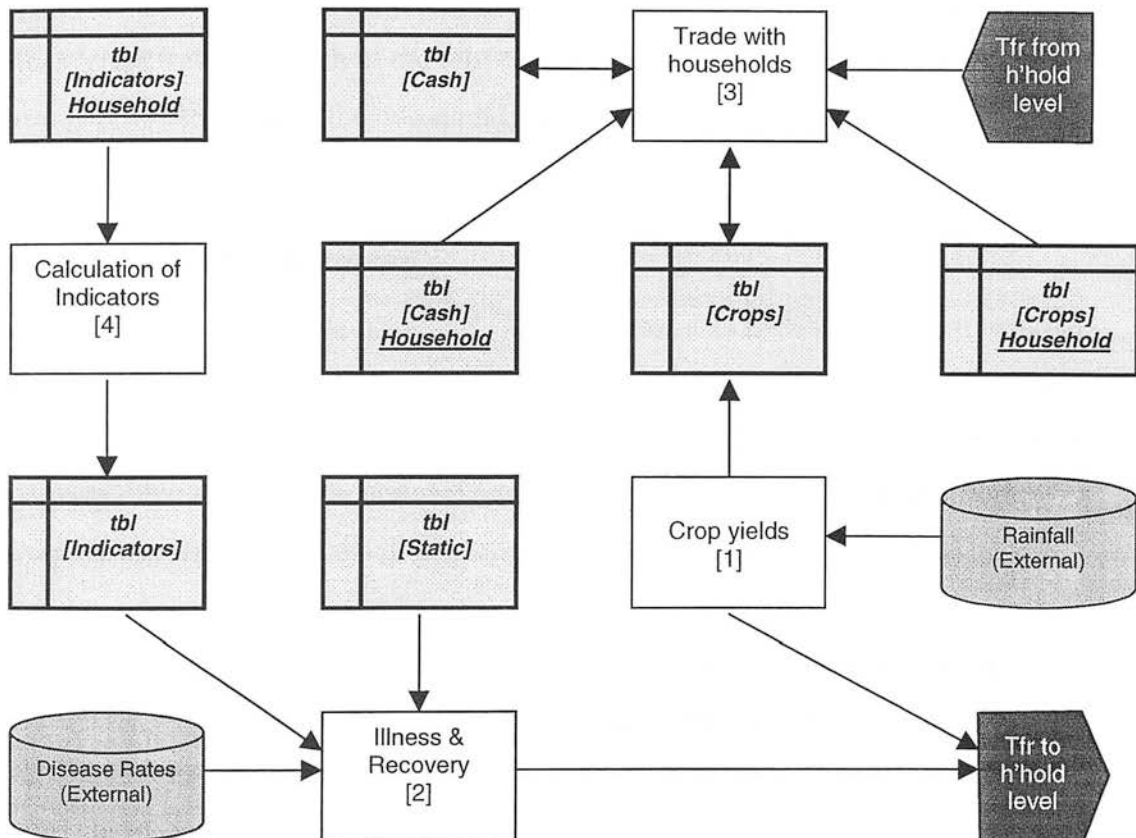


Figure 7.10 Ward level rule groups, their relationship with the tables of the population database, the short term factors and the links to the household level processing.

In the Figure 7.10 the four rule groups for the ward level of the hierarchy are numbered in processing order. Within each time step, after completing the first two rule groups for the current ward, processing is transferred to the household level. After processing all households within the current ward (described in the previous section), processing returns to the ward level to carry out rule groups [3] and [4]. The four rule groups are described briefly below.

♦ [1] Crop yields

As noted in the household section above, the calculation of crop yields is a two stage procedure. At ward level, generated rainfall is used to calculate the average crop growth for each of the four crops at each dekad, taking account of crop growth in earlier dekads. The *Crops* table is updated in the field ‘...EstimatedYieldTHa’ with this average value for each of the four crops. These fields are then accessed by the crop yields rule group in the household processing.

♦ [2] Illness and recovery

These are also two stage applications. Ward illness rates are obtained from external short term factors generated from a combination of infection rates observed in the household survey and the health statistics known as ‘T5 Form Data by Clinic’. Ward recovery rates are based on national rates modulated by the quality of health care access in the ward, as shown in the ward *Static* table.

In each time step, after processing this rule group for the ward, the processing of households within the ward commences. Only after all households within the current ward have been processed does the simulation return to the ward level and continue with rule groups [3] and [4].

♦ [3] Trade with households

This rule group is the nub of the implementation of the C.I.A.O. concept discussed in the previous chapter (see section 6.5.4). The ward level *Crops* and *Cash* tables, combined with the rules herein, are in effect the ‘central trader’ through which all inter-household and other trading by households is simulated.

Following the processing of the last household within the ward, this rule group accesses each constituent household’s *Crops* and *Cash* tables, reading the quantity and value of the sales and purchases of each of the four crops (sales only for the cash crops). The sale and purchase quantities and values of all constituent households, for

each crop, are aggregated. These aggregate amounts are recorded in the ward *Crops* and *Cash* tables in the fields as follows:

Aggregate sales quantity	to <i>Crops field</i>	'... PurchasesFromHouseholdsKg'
Aggregate sales value	to <i>Cash field</i>	'... PurchasesFromHouseholdsZD'
Aggregate purchases quantity	to <i>Crops field</i>	'... SalesToHouseholdsKg'
Aggregate purchases value	to <i>Cash field</i>	'... SalesToHouseholdsZD'

An important assumption of this framework (discussed further below) is the ranking order applied to household trades. For all household transactions, in each crop, in each time step, up to the point that all households in surplus have traded with those in deficit, or vice versa, it is assumed that inter-household trading (cf. sales / purchases to / from traders) is occurring. Thus, when this assumption is applied to the fields above, for each of the three food crops, the differences between aggregate sales and aggregate purchases are the amounts that were not satisfied by inter-household trading. These net amounts for each crop will be the balances left in the ward 'central trader' for market clearing through trade with the ward's parent agro-ecological zone's 'central trader', with prices determined by application of Vaze's (1999) model, with the G.M.B. price as the external market price. (For cash crops, as households will only make sales, there are no inter-household trades and the aggregate sales amount will be the balance for market clearing through the same route as the food crops.)

This rule group now initiates market clearing and the ward 'central trader' sells or buys crops from the parent zone's 'central trader' to restore the balance of each crop to zero i.e. market clearing is complete, with no stockholding by the 'central trader'. (The possibility of allowing stock holding by the 'central traders' is discussed in the final chapter of the thesis.)

The entries for the trade are as follows:

If balance is a net inflow:

<i>then</i> quantity balance	to <i>Crops field</i>	'... SalesToAgEcoZoneKg'
<i>and</i> value thereof	to <i>Cash field</i>	'... SalesToAgEcoZoneZD'

If balance is a net outflow:

then quantity balance to *Crops field* ‘... PurchasesFromAgEcoZoneKg’
 and value thereof to *Cash field* ‘... PurchasesFromAgEcoZoneZD’

At this point, the reasons for recording the sales and purchases separately after the aggregation procedure need explanation. For market clearing and the onward trading through agro-ecological zone, all that is required is the net balance of sales / purchases. However, this version of the framework assumes that the Zimbabwean grain pricing situation prevails. In Zimbabwe, the G.M.B. price support mechanisms comprise pan-seasonal, pan-territorial prices for the principal food and cash crops which are set at the beginning of each agricultural season. These mechanisms effectively exert an exogenous control over the prices for trades: household / household, household / traders, traders / traders and (of course) household / G.M.B. and traders / G.M.B. As discussed in section 6.4, with reference to Vaze’s findings and his model of grain trading, the effect of this is that inter-household trades will always be the preferred option for households, whether buying or selling, as it will be in both parties interest to strike a bargain at a price close to the mid-point of the G.M.B. buying / selling prices, as adjusted by the relative surplus / deficit position of the ward in aggregate. Where inter-household trades are not possible for a household (i.e. once all households in surplus have traded with those in deficit, or vice versa), the trade must be completed through a trader or the G.M.B. at a disadvantageous price compared to the inter-household striking price. This latter price will be determined by applying a modified version of Vaze’s model to allow for both G.M.B. buying and selling prices to influence market prices.

It will be seen that it is an essential feature of this framework for the extent of inter-household trades to be identified in order to correctly price the sales and purchases made by households. The procedure for this is described in section 6.4 and involves calculating the proportion of inter-household trades to total household trades at any time step by using the amounts from the previous time as a first order approximation. The retention of the aggregate sales and purchases amounts in the ward tables allows this to be carried out. The calculated proportions for each ward and each crop are then used to price the sales and purchases by households (as initiated by household

rule groups [6] and [8]) by proportionate weighting of the inter-household and household / trader prices.

As an example, if ward aggregate sales were, say, 800 kg. and aggregate purchases 1,000 kg., the difference would be assumed to be purchases from traders. If the inter-household price is, say, Z\$1.00 per kg. and the trader price is Z\$1.10, then the price applied to all household purchases will be:

Price per kg. of household purchases = $ZS(((800 \times 1.00) + (200 \times 1.10)) / 1000) = Z\1.02

(Obviously household sales will be at Z\$ 1.00, being wholly inter-household)

♦ [4] Calculation of indicators

The calculation of indicators at ward level is a simple aggregation of the household *Indicator* tables. In each ward, for all indices, the aggregation will be the mean value of the constituent households' values. For the household malnutrition class shown in the *Indicator* table of each household, the rule group will count the number of households in each class A,B,C, or Z and record this in the four fields of the parent ward *Indicator* table 'MalnutritionClass...Households#'.

At this point in the processing will pass to the next ward and the cycle of ward rule groups [1] and [2], followed by all constituent households, followed by ward rule groups [3] and [4], will be repeated until all wards within the current agro-ecological zone have been processed. Processing will then pass to the current agro-ecological zone itself.

7.4.3 Agro-ecological zone

For the agro-ecological level of the hierarchy, there are only two rule groups, both of which are processed within each agro-ecological zone after the constituent wards of that zone have been processed. They are shown in Figure 7.11 below, together with their relationship to the three dynamic zone tables and three of the ward tables of the population database.

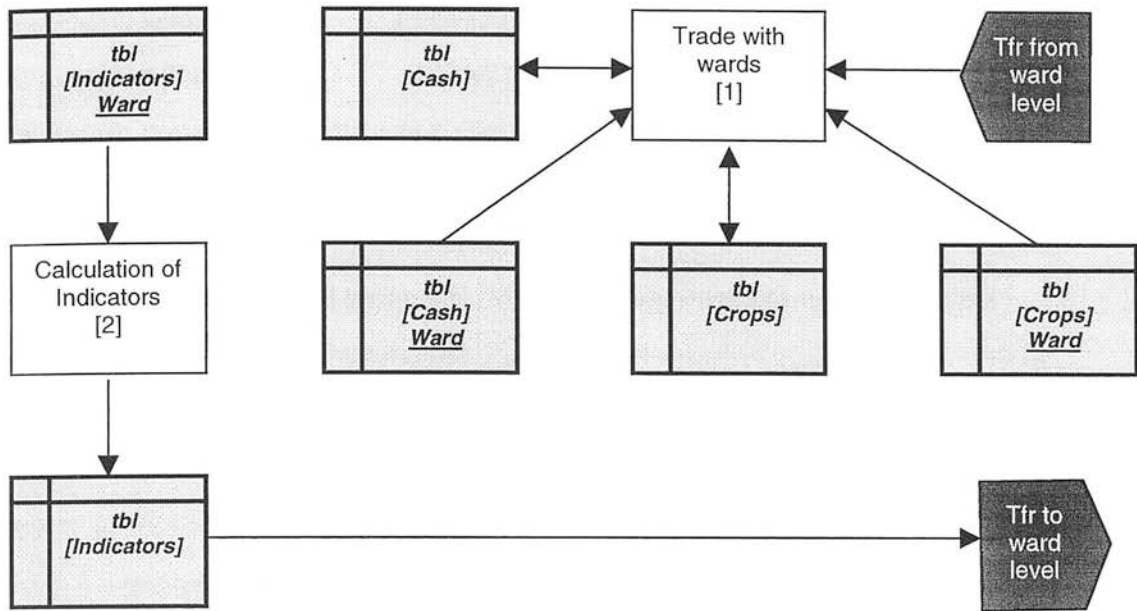


Figure 7.11 Agro-ecological zone rule groups, their relationship with the tables of the population database and the links to the ward level processing.

(Note that the *Static* table for the agro-ecological zone is omitted from the diagram as it is empty in this version of the framework and has no rules associated with it.)

The two rule groups are described briefly below.

♦ [1] Trade with wards

This rule group is similar in operation to the ‘Trade with households’ rule group at ward level and continues the implementation of the C.I.A.O. concept. The agro-ecological zone level *Crops* and *Cash* tables, combined with the rules herein, are in effect the ‘central trader’ through which all trading by wards is simulated.

Following the processing of the last ward within the agro-ecological zone, this rule group accesses each constituent ward’s *Crops* and *Cash* tables, reading the quantity and value of the sales and purchases of each of the four crops (sales only for the cash crops). The sale and purchase quantities and values of all constituent wards, for each crop, are aggregated. These aggregate amounts are recorded in the agro-ecological zone *Crops* and *Cash* tables in the fields as follows:

Aggregate sales quantity *to Crops field* ‘... PurchasesFromWardsKg’
 Aggregate sales value *to Cash field* ‘... PurchasesFromWardsZD’
 Aggregate purchases quantity *to Crops field* ‘... SalesToWardsKg’
 Aggregate purchases value *to Cash field* ‘... SalesToWardsZD’

For each of the three food crops, the differences between aggregate sales and aggregate purchases are the amounts that were not satisfied by inter-ward trading. These two net amounts for each crop will be the balance left in the agro-ecological zone ‘central trader’ for market clearing through trade with the agro-ecological zone’s parent district’s ‘central trader’. Prices will be determined by a modified version of Vaze’s model, as for wards and households. (For cash crops, as there is no consumption demand by wards on behalf of households, wards will only make sales, there will be no inter-ward trades and the aggregate sales amount will be the balance for market clearing through the same route as the food crops.)

This rule group will now initiate market clearing and the zone ‘central trader’ sells or buys crops from the district’s ‘central trader’ to restore the balance of each crop to zero. The entries for the trade are as follows:

If balance is a net inflow:

then quantity balance *to Crops field* ‘... SalesToDistrictKg’
and value thereof *to Cash field* ‘... SalesToDistrictZD’

If balance is a net outflow:

then quantity balance *to Crops field* ‘... PurchasesFromDistrictKg’
and value thereof *to Cash field* ‘... PurchasesFromDistrictZD’

♦ [2] Calculation of indicators

The calculation of indicators at agro-ecological zone level is a simple aggregation of the ward *Indicator* tables. In each agro-ecological zone, for all indices, the aggregation will be the mean value of the constituent wards’ values. For the household malnutrition class, the rule group will accumulate the number of

households in each class A,B,C, or Z for each constituent ward and record this in the four fields of the parent agro-ecological zone *Indicator* table.

At this point in the processing will pass to the next agro-ecological zone. The cycle of ward processing rule groups [1] and [2], followed by all constituent households, followed by ward processing rule groups [3] and [4], followed by agro-ecological zone processing will be repeated until all agro-ecological zones within the district have been processed. Processing will then pass to the district itself.

7.4.4 District

For the district level of the hierarchy, there are also only two rule groups, both of which are processed after the constituent agro-ecological zones of the district have been processed. They are shown in Figure 7.12 below, together with their relationship to the three dynamic district tables and three of the agro-ecological zone tables of the population database.

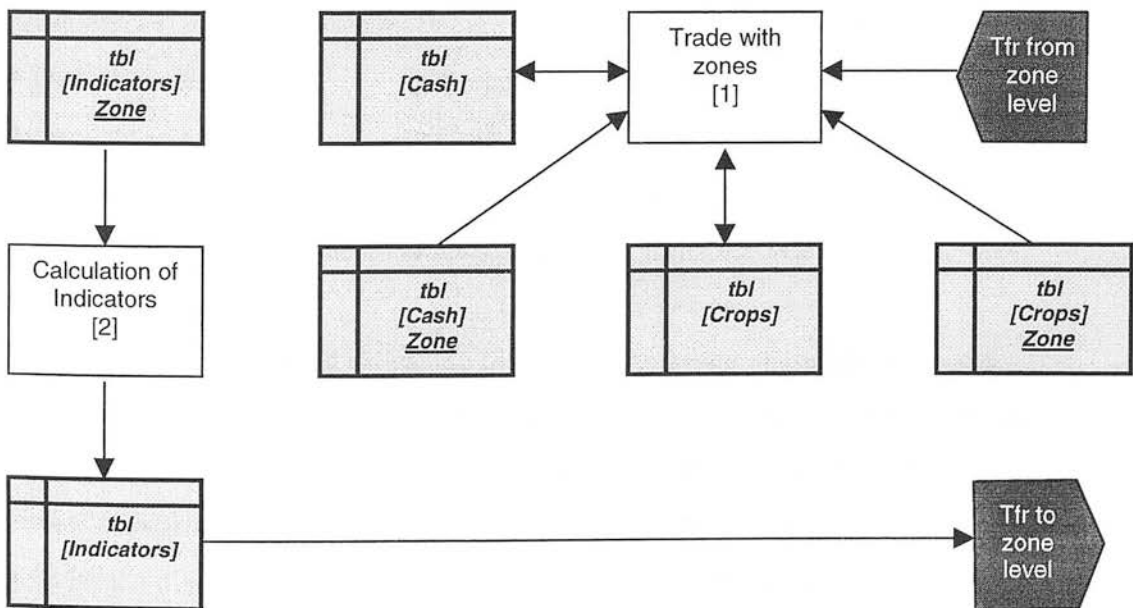


Figure 7.12 District level rule groups, their relationship with the tables of the population database and the links to the zone level processing.

(Note that the *Static* table for the district is omitted from the diagram as it is empty in this version of the framework and has no rules associated with it.)

The two rule groups are described briefly below.

♦ [1] Trade with zones

This rule group is identical in operation to the ‘Trade with wards’ rule group at zone level and continues the implementation of the C.I.A.O. concept. The district level *Crops* and *Cash* tables, combined with the rules herein, are in effect the ‘central trader’ through which all trading by zones is simulated.

Following the processing of the last zone within the district, this rule group accesses each constituent zone’s *Crops* and *Cash* tables, reading the quantity and value of the sales and purchases of each of the four crops (sales only for the cash crops). The sale and purchase quantities and values of all constituent zones, for each crop, are aggregated. These aggregate amounts are recorded in the district *Crops* and *Cash* tables in the fields as follows:

Aggregate sales quantity	to <i>Crops</i> field	‘... PurchasesFromZonesKg’
Aggregate sales value	to <i>Cash</i> field	‘... PurchasesFromZonesZD’
Aggregate purchases quantity	to <i>Crops</i> field	‘... SalesToZonesKg’
Aggregate purchases value	to <i>Cash</i> field	‘... SalesToZonesZD’

For each of the three food crops, the differences between aggregate sales and aggregate purchases are the amounts that were not satisfied by inter-zone trading. These two net amounts for each crop will be the balance left in the district ‘central trader’ for market clearing through trade with the G.M.B. and/or other large traders outwith the district, at G.M.B. prices. (For cash crops, as before, there is no consumption demand and there will be no inter-zone trades and the aggregate sales amount will be the balance for market clearing through the same route as the food crops.)

This rule group will now initiate market clearing and the district ‘central trader’ sells or buys crops from outside the district to restore the balance of each crop to zero. The entries for the trade are as follows:

If balance is a net inflow:

<i>then</i> quantity balance	<i>to Crops field</i> ‘... SalesToOutsideDistrictKg’
<i>and</i> value thereof	<i>to Cash field</i> ‘... SalesToOutsideDistrictZD’

If balance is a net outflow:

<i>then</i> quantity balance	<i>to Crops field</i> ‘... PurchasesFromOutsideDistrictKg’
<i>and</i> value thereof	<i>to Cash field</i> ‘... PurchasesFromOutsideDistrictZD’

◆ [2] Calculation of indicators

The calculation of indicators at district level is a simple aggregation of the zone *Indicator* tables. For all indices, the aggregation will be the mean value of the constituent zones’ values. For the household malnutrition class, the rule group will accumulate the number of households in each class A,B,C, or Z for each constituent zone and record this in the four fields of the district *Indicator* table.

At this point, the processing for the current time step has been completed and will pass to the next time step to restart hierarchical processing at the first ward, within the first agro-ecological zone.

7.5 Simulation engine

The simulation engine is a relatively small component of the framework, primarily responsible for the overall control of the processing. It also maintains the user interface for rule input and editing, simulation commands and output requests.

7.5.1 Processing control

Processing control is concerned with two aspects of the simulation. Firstly, it controls the time steps of the simulation, the order in which the hierarchy is processed within

each time step and the processing of the rules associated with each level of the hierarchy. Secondly, it controls the multiple runs of any simulation by resetting the population database and all temporary variables before re-starting the model.

For this version of the framework, there is only one option for time steps and that is 36 dekads (i.e. one year split into approximately ten day periods), although the user may elect to run the simulation for less than a full year. The population database is assumed to be set at time step t_0 when it is initialised. Subject to one minor change the processing of the hierarchy follows the order set out in section 6.7 ‘Simulation control’, viz:

- **Outermost loop** – timing control, dekads 1 through 36;
- **District** – 1 only;
- **Agro-ecological zone** – zones 1 through 3 (for Buhera District);
- **Ward** – wards 1 through w , where w is the total number of wards in the zone currently being processed;
- **Household** – households 1 through h , where h is the total number of households in the ward currently being processed.

The change from this planned processing order is the need to pre-process the two ward rules relating to crop growth and illness / recovery before processing the constituent households of the ward. This ensures that for these two stage applications, the first stage rule groups producing the ward level means are processed before the second stage rule groups of the constituent households.

Within each rule group, the various rules are referenced and within each rule, each line of rule code is also referenced to ensure that the encoded behaviour is invoked in the order intended by the user writing the rules. (see section 7.6.3 ‘Rule editor’ for details of rule structuring within the rule base).

7.5.2 User interface

The interface presented to the user is as shown in Figure 7.13 below. This ‘screenshot’ shows the four options (plus ‘Exit’) available to a user at the start of the program. The first three options deal with the input, maintenance and validation of the rule base and these are described in section 7.6.3 ‘Rule Editor’. The final option initiates a simulation and this is described briefly herein. On choosing to ‘Run simulation’ the user is presented with the screenshot in Figure 7.13 below.

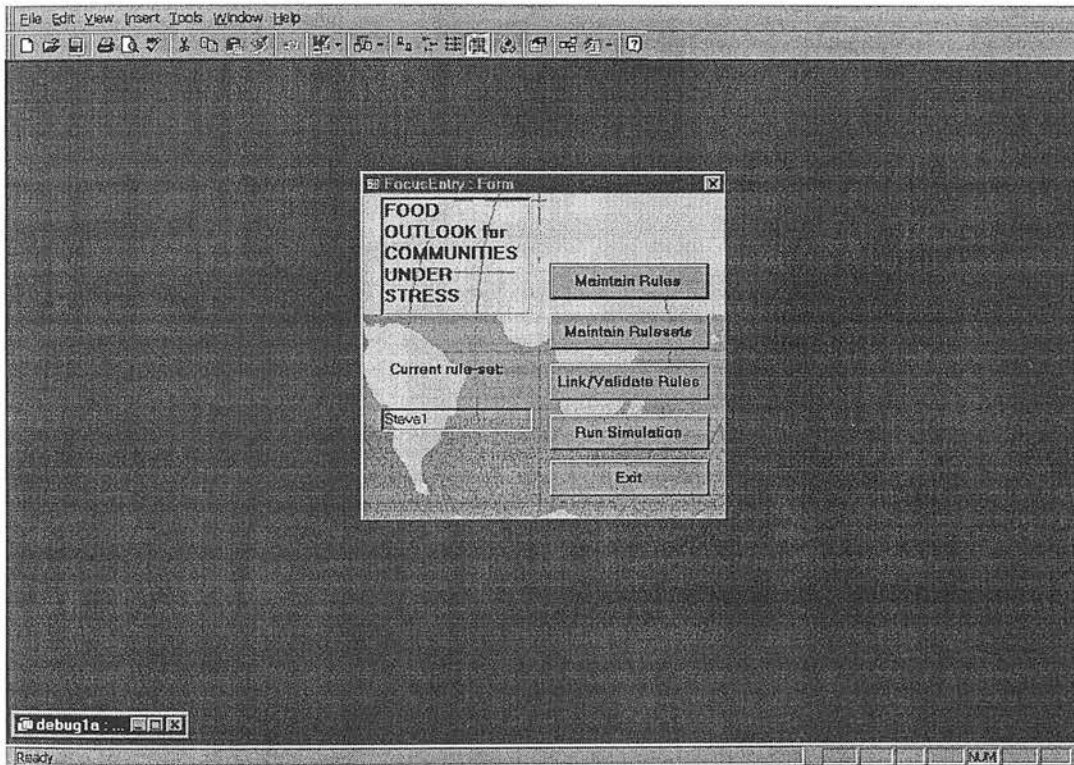


Figure 7.13 Screenshot of initial user interface for the current version of the framework.

As can be seen from the second screenshot in Figure 7.14 below, the user can opt for up to thirty six dekads, choosing either a full year’s simulation or part thereof. The user can also select one of three levels of diagnostic tracing of variables to facilitate rule testing and validation of rule groups. There are two choices of randomisation for the probability distribution functions in use. The first choice is a repeatable random number seed, which again facilitates testing and validation. The second choice is appropriate for multiple simulation runs where the user wishes to obtain stochastically

varying results for the same input conditions. This would be of particular use for creating multiple output files for statistical analysis. The ‘Depopulate’ button on the screenshot is used to manually reset the population database to its initial t_0 position. It is of particular use in testing when rules fail to work as expected and the program ‘crashes’ – an automatic re-setting of the population database would prevent the retrospective analysis of the processed data to determine the reasons for the rule failure.

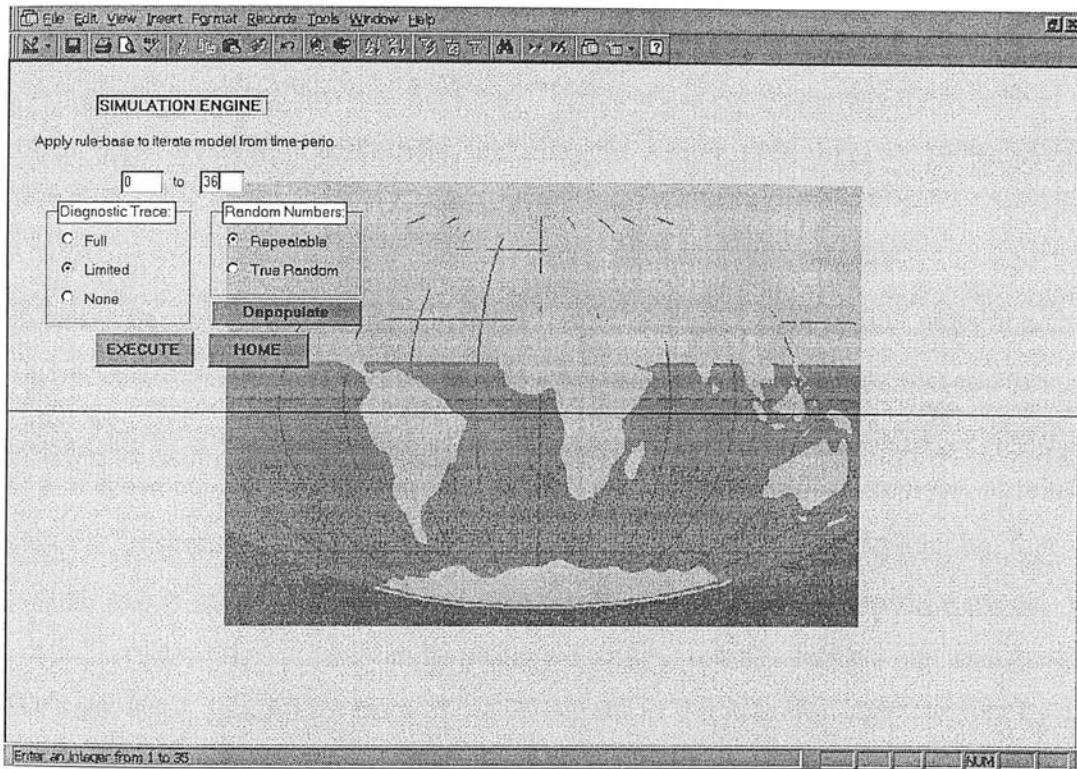


Figure 7.14 Screenshot to initiate a simulation.

7.6 Input

7.6.1 Short term factors

There are three main short term factors: rainfall, illness and economic changes (including grain prices). The design considerations for these were discussed in the previous chapter (see section 6.9) and each is discussed only briefly below.

◆ Rainfall

The links between the rule groups and the rainfall data have been shown in the description of the rule base. The data are applied to rules at ward level to produce mean ward values for crop growth. These ward means are then modulated by household factors (both static and dynamic) to produce the required household crop yields.

A procedure for generating rainfall on a ward-by-ward basis has been developed by researchers working with the author, in conjunction with colleagues from the Biological Statistical Services Scotland. This work is comprehensively described in a recent paper by Wright and others, including the author, (Wright et al. 1999). A copy of this paper is enclosed in Appendix VIII.

In summary, the methodology simulates rainfall across a set of spatial units in areas where long-term meteorological records are available for a small number of sites only. The network of meteorological stations around the Buhera District is sparse and few of these have long time series of rainfall records. Preliminary analysis of rainfall data for these stations suggested that temporal correlation was negligible, but that rainfall at any given station was correlated with rainfall at neighbouring stations. This spatial correlation structure can be modelled using a multivariate normal distribution. For each ward, rainfall for each of the 36 dekads in the year was characterised by a mean and standard deviation, which were interpolated from surrounding meteorological stations. A covariance matrix derived from a distance measure was then used to represent the spatial correlation between wards. Random numbers were then drawn from this distribution to simulate rainfall across the wards in any given dekad. Cross-validation of estimated dekadal rainfall distribution parameters against those observed at the one meteorological station within the district suggests that the methodology works well.

Using this procedure, rainfall ‘scenarios’ enable users to select different types of yearly rainfall profiles, not only ‘Good’, ‘Average’, ‘Poor’ and ‘Drought’ (i.e. using end-of-year aggregate rainfall), but also more complex situations such as ‘Poor early

rains’ and ‘Drought mid-season’, where dynamic rainfall patterns provide a more realistic input to the simulations.

♦ **Illness**

Illness and recovery data are used by the simulation framework in much the same way as the rainfall data. The links between the rule groups and illness and recovery data have been shown in the description of the rule base, with ward level means modulated by static and dynamic household factors to produce the required illness and recovery rates within each cohort of the household.

Procedures for generating illness and recovery rates from district and clinic data have been partially completed, but further assistance is required from medically qualified colleagues in one of the collaborating institutions to reclassify the published morbidity and mortality statistics by cohort. Analysis of the household survey data will support this reclassification. This work is closely related to the development of the illness and recovery rule groups at ward and household level, which themselves are not yet complete. One aspect of this part of the work that has been completed is the procedure for converting the clinic statistics for the study district to morbidity and mortality data on a ward basis. This involves estimating the ‘catchment’ for each clinic from known attendance, physical access and demographic data for the wards surrounding each facility. Using a G.I.S. methodology, the clinic statistics are in effect re-referenced by ward to give data that can be used by the simulation.

♦ **Economic changes (including grain prices)**

Reference has been made both in the previous chapter (section 6.5) and the description of the trading rules at ward level to the exogenous price support provided by the G.M.B.. This support takes the form of setting buying and selling prices for the principal crops before the agricultural year commences and maintaining these during the year, regardless of production. This has the effect of making the G.M.B. a buyer and seller of last resort. As Vaze (1999) has demonstrated traders are influenced by the G.M.B. prices in setting their own prices, which vary with localised production conditions and the expected alternative transaction costs that households

would incur in transporting crops to/from the G.M.B. depot. Under such pricing conditions, households will always prefer inter-household trades as these will reflect localised production conditions, but will have nil transaction costs.

A modified version of Vaze's (1999) model will be used in the trading rule group of each hierarchical level to determine prices in each ward of Buhera. The short term factors required as input to this model, for each crop, will be: the G.M.B. buying and selling prices fixed for the season; the interest rate r ; the transfer costs between wards m_w ; the transfer costs between zones m_z ; and, the transfer costs d_w between the nearest G.M.B. depot and the wards.

Other important economic variables include urban unskilled wages and living costs (for determining the net cash available as remittances), state pensions, school fees, health fees, bus fares etc.. In this version of the framework, these are set through the relevant rule groups, although future versions may include these in the district level *Static* table as they will not vary for any location therein.

Although the interest rate is explicitly included in Vaze's model of pricing, no other adjustment for inflation has been incorporated within the framework structure. With high levels of inflation currently in Zimbabwe (in common with many other sub-Saharan countries) this will have to be considered in future versions.

7.6.2 Initial population database

As noted at the start of this chapter, the population database effectively comprises the *data* upon which the simulation *experiment* is performed. In the early days of the collaborative research project, it had been expected that secondary data, in the form of detailed census files, would be obtained to be used as the *data* for the simulation, whatever form the modelling framework was to take. As noted in section 4.5.3, these census files were not made available and only limited, summary ward statistics about the study district were provided towards the end of the field visits to Zimbabwe. The household survey was planned to provide only sufficient data to support the development of nutritional, physiological and micro-economic sub-models for implementation within the framework. In an attempt to compensate for the

shortcomings in the census data, the scope of the field survey was enhanced to collect extra data about the sample households.

However, the data coverage of the district overall remained fragmentary with a mix of primary survey data for ten of the thirty four wards, together with census and other various secondary data, in different units of aggregation, for the whole district. This fragmentary coverage of the study district presented difficulties for the overall development of the framework, because without a representative file of households for the whole district, the simulation of spatial variability would be compromised at the outset. It was thus necessary to develop a method to create such a representative file from the limited data sources available. With this second framework design, this method was directed towards creating the initial population database, with its hierarchical structure and containing a representative 10% sample of households for each of the thirty four wards in Buhera.

The method chosen was to extrapolate household characteristics from the household survey for all thirty four wards (i.e. not just for the ten wards surveyed in the sample) by matching the unsurveyed wards to the 'nearest' surveyed ward. 'Nearest' was not based on geographical location, but on cluster analysis of ward characteristics. These ward characteristics were obtained from census and other secondary data sources. After matching unsurveyed to surveyed wards, the required number of households for each ward (per the 1992 Census) was extrapolated from the survey data, using a cross-correlation matrix to allow for correlation between characteristics.

This method is described below and in a recent joint paper (Gundry et al., 1999). The overall diagram for the method is shown in Figure 7.15 below.

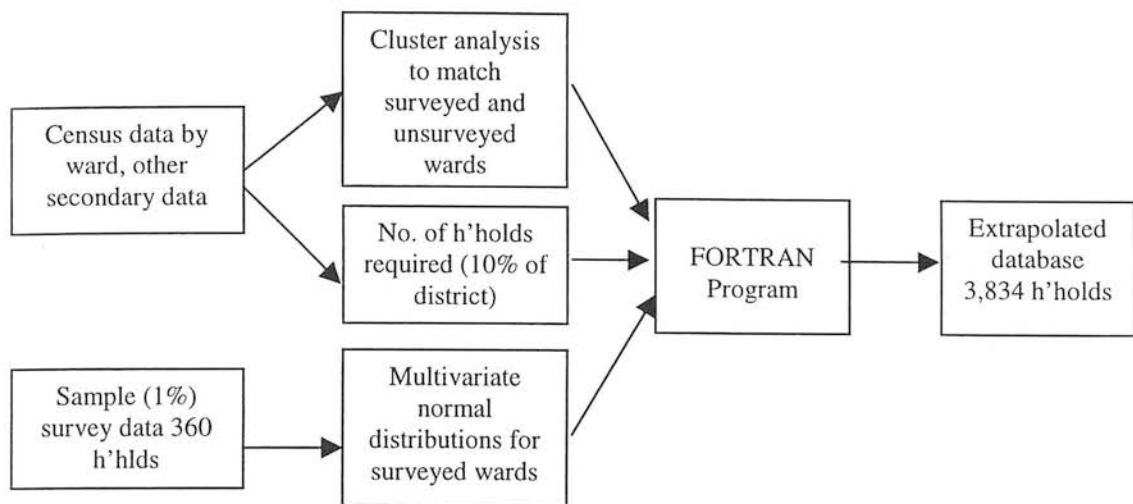


Figure 7.15 Diagram of the method used to match unsurveyed and surveyed wards in order to extrapolate the population database from the household survey.

◆ Matching unsurveyed and surveyed wards

Using the secondary data referred to above, seventeen variables were selected and used to characterise all the wards in Buhera. The variables chosen, the variable name used in the subsequent algorithm (in parentheses), a brief description of each and the source of the data, were as follows:

1. **Healthcare access ('ACCHLTH')** - the mean index of access to health centres, medical outreach points and hospitals, based on distance and transport availability. A G.I.S. was used to compute a composite measure of distance and transport links to three types of health facility. A higher value corresponded to a nearer facility and/or better transport links. The computed measure was standardised and the index for each ward-facility pair expressed as a z-score from the mean. This z-score (which obviously can take negative values) was then multiplied by the expert weighting given to the importance (from the standpoint of nutritional status) of each of the three facility types. For each ward, the value shown in the 'ACCHLTH' column is the aggregate of the product of the indices and weightings for each facility to which the ward had access.

2. **Distance to water source ('ACCWATER')** - the mean distance to the usual water source, in metres. From 1992 census.
3. **Age of household head ('AGEHH')** - the mean age of the household head. From 1992 census.
4. **Agricultural income ('AGINC')** - the mean proportion of households having solely agricultural income sources. From 1992 census.
5. **Dependency ratio ('DEPENDCY')** - the mean ratio of adults to children and elderly. From 1992 census.
6. **Market access ('DISTMKT')** - the mean distance in km. to the nearest town, business centre or growth point where a street market exists. Computed from maps and Agritex (agricultural extension service) data using a geographical information system.
7. **Proportion of female-headed households ('FEMALEHH')** - the mean proportion of households having a female resident household head. From 1992 census.
8. **Fuel used for cooking ('FUELWOOD')** - the mean proportion of households using wood or charcoal as the principal source of fuel for cooking. From 1992 census.
9. **Housing type ('HOUSGIND')** - the mean index of housing type: traditional, modern or mixed, based on usage of materials and method of construction. N.B. Higher score is poorer housing. From 1992 census.
10. **Maize grown ('MAIZEPPN')** - the mean proportion of maize grown out of total food crops. Computed from Agritex (agricultural extension service) data.
11. **Non-agricultural income ('NONAGINC')** - the mean proportion of households having solely non-agricultural income sources. From 1992 census.
12. **Population density ('POPNDENS')** - the number of residents per sq. km.. Computed from 1992 census data.
13. **Type of water source ('PRWATER')** - the mean index of type of water source and temporal access thereto i.e. protected (tap, well, borehole) or unprotected

(lake, river or stream) for whole or part of year. N.B. Higher score is better water source. From 1992 census.

14. **Sanitation type ('SANITIND')** - the mean index of sanitation based on facility type: flushing WC (very rare), 'Blair' lavatory (fly-unfriendly dry cubicle), pit latrine or none. N.B. higher score is poorer sanitation. From 1992 census.
15. **Housing size ('SEPRMS')** - the mean proportion of households having separate living and sleeping rooms. From 1992 census.
16. **Sex ratio ('SEXRATIO')** - the mean ratio of females to males for resident household members. From 1992 census.
17. **Household size ('SIZEHHL')** - the mean number of resident household members. From 1992 census.

The raw data for these seventeen variables, for each of the thirty six wards of the study district, are shown in Table 7.3 overleaf. Note that in table 7.3, the two wards numbered 35 and 36 are the urban wards Murambinda and Dorowa. Their characteristics for the majority of the variables are noticeably different to the remainder of the wards, all of which are rural. These two urban wards were therefore excluded from the matching process.

♦ **Standardising the characteristics**

The variables were used in a cluster analysis to group together the unsurveyed wards with those survey wards 'most closely matching'. This closeness of match is the squared Euclidean distance between wards in n -dimensional space, for the given n characteristics. It is calculated as the sum of the squared differences between the values for each of the n characteristics for the two wards whose closeness is being measured. Thus it is important for each variable to have a common scale, so that artificial weights are not introduced when the closeness is calculated. Each of the seventeen variables was therefore standardised, with a mean of zero and standard deviation 1. The standardised variables are shown in Table 7.4.

Ward No	Ward Name	In field survey?	AgZoneID	ACCHLTH	ACOWATER	AGEHH	AGINC	DEPENDCY	DISTMKT	FEMALEHH	FUELWOOD	HOUSGIND	MAIZEPPN	NONAGINC	POPNDENS	PRWATER	SANITIND	SEPRMS	SEKVRATIO	SIZEHLD
1	Mudzamiri	No	3	-5.09	631	46.7	0.810	0.431	5.79	0.502	0.988	0.767	0.957	0.055	41.50	0.587	0.830	0.042	1.44	4.95
2	Chapwanya	Yes	3	6.97	666	46.1	0.837	0.433	8.64	0.505	0.998	0.851	0.907	0.059	57.36	0.323	0.868	0.042	1.42	5.21
3	Garamwera	No	3	10.64	480	48.2	0.689	0.450	5.63	0.484	0.969	0.743	1.000	0.078	38.25	0.591	0.658	0.033	1.25	4.85
4	Nerutanga	No	3	13.38	734	45.7	0.848	0.418	5.20	0.496	0.997	0.740	0.933	0.040	43.28	0.235	0.727	0.038	1.34	5.12
5	Makume	Yes	3	18.67	544	43.4	0.689	0.494	7.00	0.453	0.961	0.584	0.975	0.097	46.04	0.513	0.611	0.067	1.14	4.72
6	Makumbé	No	3	14.25	708	47.5	0.679	0.459	5.18	0.492	0.969	0.748	0.953	0.067	41.48	0.445	0.840	0.028	1.20	5.28
7	Munyira	No	3	7.01	799	44.7	0.744	0.459	4.89	0.521	0.984	0.694	0.905	0.073	52.16	0.590	0.731	0.031	1.33	5.39
8	Mombeyarara A	No	3	21.94	578	45.0	0.762	0.436	3.92	0.517	0.979	0.760	0.724	0.075	44.92	0.729	0.746	0.036	1.31	5.13
9	Mombeyarara B	No	3	21.33	587	47.2	0.829	0.418	4.25	0.530	0.996	0.811	0.776	0.050	55.06	0.586	0.766	0.025	1.40	5.02
10	Chitsunge	No	3	5.61	634	45.0	0.785	0.422	4.88	0.480	0.991	0.759	0.881	0.067	39.81	0.483	0.830	0.021	1.32	4.70
11	Chimombe A	No	3	1.75	525	44.9	0.588	0.444	4.59	0.495	0.941	0.562	0.893	0.100	64.90	0.527	0.598	0.073	1.41	5.14
12	Chimombe B	No	3	6.96	742	45.9	0.580	0.435	4.92	0.507	0.975	0.661	0.750	0.114	52.50	0.553	0.688	0.040	1.36	5.08
13	Chimombe 'B	No	4	6.44	697	44.7	0.705	0.393	6.79	0.569	0.991	0.787	0.690	0.056	35.94	0.691	0.887	0.032	1.55	5.29
14	Chiweshe	No	4	4.19	802	43.3	0.709	0.394	5.66	0.549	0.990	0.764	0.373	0.051	33.27	0.530	0.796	0.027	1.50	5.16
15	Neshava	Yes	3	12.15	814	44.2	0.783	0.427	4.58	0.531	0.994	0.776	0.654	0.054	49.93	0.420	0.859	0.022	1.32	5.15
16	Murambinda	No	3	21.26	536	44.1	0.824	0.418	5.64	0.505	0.994	0.797	0.875	0.059	60.50	0.388	0.825	0.021	1.42	5.44
17	Mudinzwá A	Yes	3	4.61	754	44.2	0.823	0.388	7.21	0.558	0.995	0.839	0.492	0.044	39.59	0.622	0.848	0.026	1.53	5.22
18	Nechavava	Yes	4	3.78	592	44.4	0.775	0.400	8.17	0.533	0.994	0.808	0.656	0.056	38.95	0.566	0.913	0.025	1.45	5.18
19	Mudinzwá B	No	4	3.11	702	44.2	0.728	0.415	5.15	0.516	0.994	0.767	0.620	0.057	44.60	0.594	0.794	0.029	1.40	5.37
20	Mabvuregudo	Yes	4	11.67	711	45.7	0.876	0.414	4.92	0.493	0.989	0.824	0.691	0.038	30.39	0.612	0.853	0.024	1.36	5.23
21	Chikuwa	No	4	8.85	840	44.6	0.791	0.394	5.13	0.535	0.988	0.820	0.738	0.053	43.48	0.503	0.869	0.019	1.45	5.25
22	Makuvise	No	4	-1.48	654	43.7	0.831	0.390	5.04	0.530	0.984	0.837	0.140	0.037	49.23	0.657	0.892	0.021	1.51	5.58
23	Betera	No	4	0.61	661	43.4	0.788	0.388	6.55	0.533	0.990	0.780	0.529	0.049	23.12	0.603	0.850	0.029	1.59	4.96
24	Murwira	Yes	4	3.90	831	44.1	0.545	0.384	9.95	0.543	0.995	0.839	0.465	0.055	38.03	0.646	0.847	0.019	1.61	5.30
25	Mawire	No	4	-2.45	702	43.6	0.589	0.394	4.17	0.507	0.984	0.825	0.208	0.040	41.32	0.548	0.843	0.016	1.46	5.31
26	Chirozva A	No	4	-2.12	782	43.0	0.199	0.384	6.57	0.513	0.991	0.849	0.220	0.024	33.58	0.538	0.910	0.027	1.58	5.35
27	Chirozva B	Yes	5	-8.58	593	43.4	0.507	0.373	4.80	0.568	0.991	0.815	0.244	0.044	34.27	0.297	0.803	0.011	1.70	5.59
28	Mushumba East	No	5	-3.45	644	43.0	0.810	0.376	8.24	0.561	0.996	0.871	0.145	0.040	30.11	0.379	0.878	0.019	1.58	5.47
29	Mushumba West	No	4	0.33	521	43.1	0.722	0.381	9.73	0.528	0.988	0.818	0.198	0.049	43.73	0.545	0.825	0.016	1.61	5.19
30	Chimombe West	No	5	-0.02	885	42.8	0.829	0.377	10.23	0.542	0.991	0.873	0.140	0.040	30.36	0.747	0.823	0.020	1.42	5.44
31	Mutiusinazita	No	5	5.24	607	43.1	0.552	0.389	11.81	0.563	0.986	0.862	0.011	0.036	30.82	0.879	0.823	0.022	1.56	5.47
32	Chimombe East	Yes	5	-6.81	667	44.3	0.760	0.383	9.33	0.532	0.996	0.921	0.211	0.043	21.88	0.582	0.932	0.024	1.61	5.34
33	Chimombe West	No	5	1.90	842	42.6	0.830	0.389	13.07	0.565	0.995	0.890	0.140	0.038	25.90	0.719	0.890	0.018	1.49	5.43
34	Chimutsa East	Yes	5	-0.46	836	41.4	0.547	0.466	10.31	0.472	0.973	0.717	0.082	0.115	30.64	0.702	0.661	0.062	1.14	5.54
35	Dorowa	Exclude	3	3.28	30	35.2	0.107	0.608	0.58	0.102	0.009	0.000	0.000	0.335	850.00	1.000	0.002	0.049	0.80	3.74
36	Murambinda (u)	Exclude	3	716.63	102	33.7	0.157	0.665	1.52	0.332	0.539	0.031	0.000	0.366	608.40	0.971	0.175	0.102	1.31	3.94
		Mean		5.47	685	44.44	0.717	0.412	6.70	0.521	0.986	0.787	0.564	0.057	40.79	0.557	0.809	0.030	1.43	5.23
		Std Dev		7.93	108	1.50	0.138	0.030	2.40	0.029	0.012	0.078	0.323	0.022	10.40	0.135	0.086	0.014	0.14	0.22

Table 7.3 Seventeen variables characterising the surveyed and unsurveyed wards of Buhera District (raw data; unstandardised).

(Note that some duplication of ward names exists in the two tables, which is present in the source data from the Central Statistics Office in Zimbabwe.)

◆ Cluster analysis

Two methods were used to measure 'closeness'. Initially, a simple Fortran computer program was written which calculated the Euclidean distance between every pair of surveyed / unsurveyed wards, as mapped across the seventeen dimensions of the standardised characteristic variables. However, this method did not provide any post processing analysis of the goodness of fit of the ward pairings. It was also felt to be less flexible than use of a standard statistical package.

A second method was therefore developed using the statistical procedure of *k*-means clustering, a subset of cluster analysis, which allows the user to specify not only the number of clusters required from the analysis, but also the initial locations of the cluster centres. Most standard statistical packages (the author used SPSS Version 9.0) will support cluster analysis. Thus, for the application herein, the 34 wards are required to be grouped into ten clusters, one cluster per surveyed ward. The initial cluster centres correspond to the values of the standardised characteristic variables for each of the surveyed wards. These initial cluster centres are shown in Table 7.5 below.

	Cluster									
	1	2	3	4	5	6	7	8	9	10
ACCHLTH	-.75	-1.55	-1.77	-.20	.78	-.21	-.11	.84	1.66	.19
ACCWATR	1.39	-.16	-.85	1.35	.24	-.86	.63	1.18	-1.30	-.18
AGEHH	-2.04	-.09	-.73	-.21	.80	-.06	-.18	-.14	-.71	1.10
AGINC	-1.23	.31	-1.52	-1.24	1.16	.42	.77	.48	-.20	.87
DEPENDCY	1.77	-.96	-1.29	-.93	.06	-.40	-.80	.49	2.69	.68
DISTMKT	1.51	1.09	-.80	1.35	-.74	.61	.21	-.88	.12	.81
FEMALEHH	-1.69	.36	1.59	.74	-.97	.40	1.25	.33	-2.34	-.56
FUELWOOD	-1.11	.80	.38	.71	.22	.63	.71	.63	-2.10	.96
HOUSGIND	-.90	1.73	.37	.68	.48	.28	.68	-.14	-2.61	.83
MAIZEPPN	-1.49	-1.09	-.99	-.31	.39	.28	-.22	.28	1.27	1.06
NONAGINC	2.62	-.66	-.61	-.11	-.89	-.07	-.61	-.16	1.80	.07
POPNDENS	-.98	-1.82	-.63	-.27	-1.00	-.18	-.12	.88	.50	1.59
PRWATER	1.08	.19	-1.93	.66	.41	.07	.48	-1.02	-.33	-1.74
SANITIND	-1.73	1.43	-.07	.44	.51	1.21	.45	.58	-2.31	.69
SEPRMS	2.29	-.39	-1.31	-.74	-.39	-.32	-.25	-.53	2.64	.88
SEXRATIO	-2.14	1.30	1.91	1.30	-.53	.12	.73	-.79	-2.15	-.07
SIZEHLD	1.38	.48	1.61	.33	-.01	-.23	-.07	-.36	-2.31	-.08

Table 7.5 Centres of the initial clusters, as reported by the SPSS *k*-means cluster analysis.

The 'locations' in seventeen dimensions of each of the 34 wards, unsurveyed and surveyed, are then input to the procedure. The algorithm then matches each ward to the closest cluster centre. At this point each cluster has at least one ward (the surveyed ward used as its centre), and any unsurveyed wards located nearest thereto. The algorithm then recomputes the cluster centres, which will have moved from the initial position specified to the centroid of the locations of all the wards comprising that cluster. It then repeats the matching part of the algorithm and recomputes the cluster centres, which will only change if wards are now closer to a revised cluster centre than to the original position. This iteration continues until a stable cluster set is achieved. For this application, there were three iterations and the iteration history is shown in Table 7.6 below.

Iteration History^a

Iteration	Change in Cluster Centers									
	1	2	3	4	5	6	7	8	9	10
1	1.778	2.808	1.821	1.287	1.299	2.236	1.851	1.16E-05	1.578	1.08E-05
2	.000	.000	.494	.607	.000	.000	.000	.000	.663	.000
3	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

a. Convergence achieved due to no or small distance change. The maximum distance by which any center has changed is .000. The current iteration is 3. The minimum distance between initial centers is 2.304.

Table 7.6 Iteration history for the SPSS *k*-means cluster analysis.

Once a stable cluster set is achieved, the cluster membership is reported. Table 7.7 below shows the ten final clusters and the wards included within each cluster.

Cluster		Surveyed		Unsurveyed						TOTAL
1	Wards	2	16							2
	AgZones	3	3							1
2	Wards	5	3	11						3
	AgZones	3	3	3						1
3	Wards	15	4	7	9	12				5
	AgZones	3	3	3	3	3				1
4	Wards	17	13	14	21	22	23	25		7
	AgZones	3	4	4	4	4	4	4		2
5	Wards	18	1	19	29					4
	AgZones	4	3	4	4					2
6	Wards	20	6	8	10					4
	AgZones	4	3	3	3					2
7	Wards	24	26	31						3
	AgZones	4	4	5						2
8	Wards	27								1
	AgZones	5								1
9	Wards	32	28	30	33					4
	AgZones	5	5	5	5					1
10	Wards	34								1
	AgZones	4								1

Table 7.7 Final cluster membership from the SPSS *k*-means cluster analysis.

It will be seen from Table 7.7 above that each cluster has one surveyed ward and between zero and six additional, unsurveyed wards. Thus, each unsurveyed ward is effectively ‘matched’ to a surveyed ward by cluster membership. This table also shows the agroecological zone in which each ward is located. It will be noted that the reported clusters appear to be well defined for this agroecological zone variable, despite its exclusion as a characterising variable in the cluster analysis. This lends support to the use of agroecological zone in the sample stratification and the use of these zones as separate hierarchical levels in the simulation model.

The statistical package used by the authors also provides a post-processing ANOVA report of the clusters. This is shown in Table 7.8 below.

Variable	Cluster		Error		F	Sig.
	Mean Sq	df	Mean Sq	df		
ACCHLTH	2.341	9	.497	24	4.709	.001
ACCWATR	2.017	9	.619	24	3.262	.010
AGEHH	1.955	9	.642	24	3.047	.014
AGINC	2.461	9	.452	24	5.441	.000
DEPENDCY	3.009	9	.247	24	12.207	.000
DISTMKT	2.571	9	.411	24	6.259	.000
FEMALEHH	2.668	9	.375	24	7.123	.000
FUELWOOD	2.694	9	.365	24	7.388	.000
HOUSGIND	2.767	9	.338	24	8.196	.000
MAIZEPPN	2.798	9	.326	24	8.584	.000
NONAGINC	2.432	9	.463	24	5.256	.001
POPNDENS	2.549	9	.419	24	6.085	.000
PRWATER	1.682	9	.744	24	2.260	.054
SANITIND	2.898	9	.288	24	10.049	.000
SEPRMS	2.490	9	.441	24	5.644	.000
SEXRATIO	2.960	9	.265	24	11.178	.000
SIZEHHLD	2.035	9	.612	24	3.326	.009

Table 7.8 Post-processing ANOVA for the cluster analysis of 34 wards.

The ANOVA procedure uses a one way analysis of variance that shows the between-cluster mean square in column 2 and the within-cluster mean square in column 4. The ratio of these two mean squares is the usual ANOVA F statistic. (The significance levels reported in column 7 should be ignored.). It can be seen from the table that the

characteristics of DEPENDCY, SEXRATIO and SANITIND differ most across the ten clusters, with small differences for PRWATER, AGEHH, ACCWATER and SIZEHLD. The other ten characteristics show intermediate levels of difference across clusters.

◆ Data extrapolation

After completing the matching of unsurveyed wards to the surveyed wards with the cluster analysis described above, the data required for the sample can be extrapolated from the household survey data. As discussed in section 7.3, the population database contains a 10% sample of all households in Buhera (other than the two urban wards). Thus, the required number of households is 3,834, each of which has 7 tables of data in the population database. In all, there were 54 variables to be derived, of which 51 are extrapolated from the household survey data. The remaining three variables require to be estimated from opinions of local experts, collaborating in the research. This task is outstanding.

Before extrapolation, it was necessary to analyse the household data and compute the mean and standard deviation for each of the 51 variables, for each of the 10 surveyed wards. Independent extrapolation from each variable was not appropriate as the variables are known to show substantial correlation. In addition, therefore, a cross-correlation matrix was created for each surveyed ward. A Fortran computer program written to extrapolate the required number of households' data, from an input file of descriptors: correlations, standard deviations and means. The program was run for each of the 34 wards, using the appropriate descriptors for the household sample data of the matched ward. The extrapolation program produces an output file in text format, which was then converted to the database format used for the population database.

The method of extrapolation assumed that ward characteristics are normally distributed and are unweighted by the sample frame used. It seems doubtful that these assumptions are valid, although the implications for changing the weights used in the cluster analysis are currently being investigated. Possibly of greater concern is the assumption of normality of the household survey data used in the extrapolation.

Some of the household survey data are known to exhibit marked skewness and the categorical and boolean variables are obviously not normally distributed. Possible procedures such as transformation of the distributions prior to extrapolation could be used to mitigate the problem. In particular, for the boolean variables the following method may offer an improvement: (1) Tabulate all possible combinations of 0/1 for the boolean variables and from the data calculate the probability of their occurring for each ward; (2) For each combination, calculate the parameters of the multivariate normal distribution for the other variables for each ward (this is the distribution of all the other variables conditional on a given combination of the binary variables); (3) Simulate by generating a set of values for the binary variables using the relevant probabilities, then generate the other variables from the relevant conditional distribution. This procedure could easily be extended to variables with more than two categories and is currently being evaluated, together with various transformation routines for the non-boolean, non-categoric data.

Additional work on this method of creating the households and the initial values of the data in the tables of the population database is currently in progress. With the exception of the ward *Static* table, data for the other levels of the hierarchy are trivial to input being either identifying names or zero values. Each ward static table requires ten variables to be input to describe various qualitative environmental, agricultural and health characteristics and these will be determined by analysis of secondary data. This task is outstanding.

7.6.3 Rule editor

The rule editor controls the input, editing and validating of the rules entered by the users of the framework. These functions are described briefly below.

Each implementation will probably involve several users inputting rules and needing to test their own work against the other rules and the data. To enable this to be carried out independently by users, a structure has been defined for controlling single and multiple rules within the rule base. The rule base will hold *Rule Sets*, *Rule Groups*, *Rules* and *Lines*, as outlined below:

- **Rule Set** – a complete set of *RuleGroups* (at least 1 *RuleGroup* per level of the hierarchy) which will allow the simulation to run. Specific to each user.
- **Rule Group** – a group of *Rules* which manipulate one particular aspect of behaviour for one level of the hierarchy e.g. ALLOCATION_OF_LABOUR_H ('H' identifies a rule group as associated with the household level).
- **Rule** – One or more *Lines* of code, which together define all outcomes for every possible input condition for the variable within the level of the hierarchy being processed e.g. ESTIMATE_SURPLUS_H.
- **Line** – An individual statement as encoded by the rule editor.

Whilst it is not the purpose of this thesis to describe the detail of the computer system written to implement the framework, it will be useful to provide a series of screen images to give the reader an idea of the facilities available for the input and maintenance of rules. The series of screenshots are Figures 7.16 through 7.23.

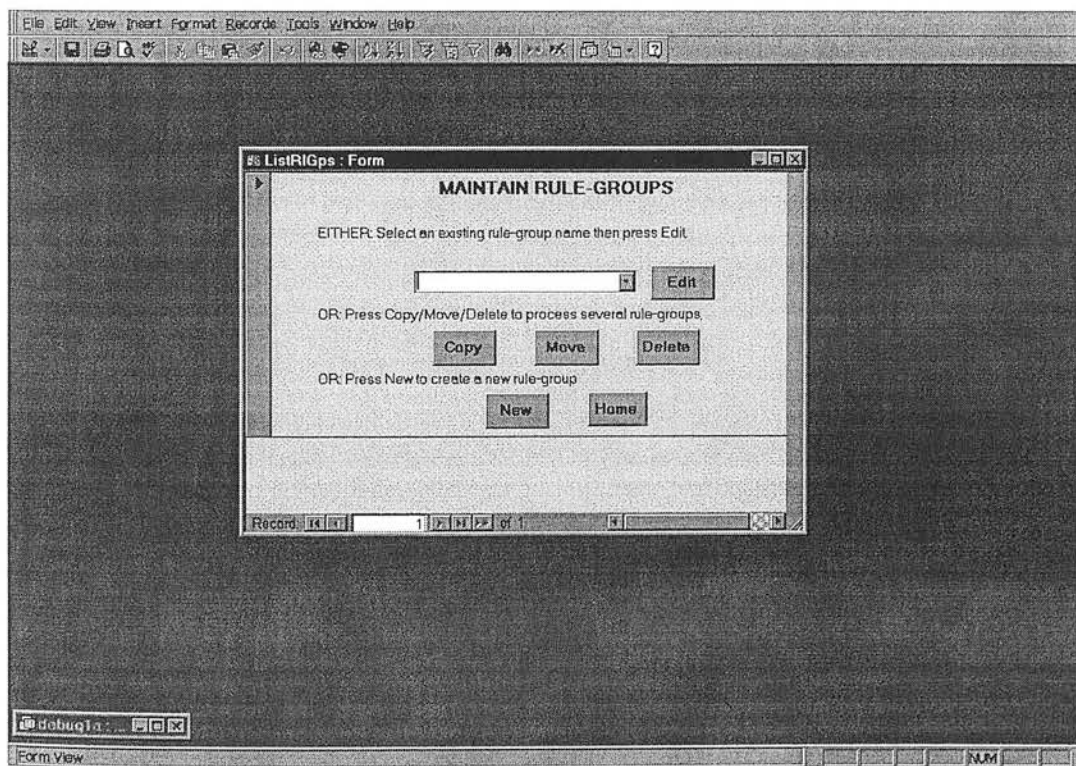


Figure 7.16 Screenshot for input and maintenance of rule groups.

The screenshot shows a software window titled "ADD A NEW RULE-GROUP". The window has a menu bar with "File", "Edit", "View", "Insert", "Format", "Records", "Tools", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area contains the following fields and controls:

- Group ID:** A text box containing "autoNumber".
- Group Name:** An empty text box.
- Hierarchy Level:** A dropdown menu showing "Household".
- Firing Phase:** A group of four radio buttons:
 - ☐ Before any entity at current level
 - ☒ For each entity at current level, but before any lower-level entity
 - ☐ For each entity at current level, but after all lower-level entities
 - ☐ After all entities at current level
- Process After Group:** A dropdown menu.
- ProcOrder:** A text box.
- Buttons:** "Add Rules", "Add More Groups", "Back to List", and "Cancel".

At the bottom of the window, there is a status bar showing "Record: 14 of 1" and "User's mnemonic for the group: NUM".

Figure 7.17 Screenshot for inputting a new rule group.

The screenshot shows a software window titled "ADD A NEW RULE". The window has a menu bar with "File", "Edit", "View", "Insert", "Format", "Records", "Tools", "Window", and "Help". Below the menu bar is a toolbar with various icons. The main area contains the following fields and controls:

- Rule ID:** A text box containing "11".
- Rule-group ID:** A text box containing "0".
- Rule Name:** An empty text box.
- Process after rule:** A dropdown menu.
- Process Order:** A text box.
- Buttons:** "Add Lines", "Add More Rules", "Back to Group", and "Cancel".

At the bottom of the window, there is a status bar showing "Record: 14 of 1" and "External ID of subgroup: NUM".

Figure 7.18 Showing the screenshot to add a new rule within a rule group

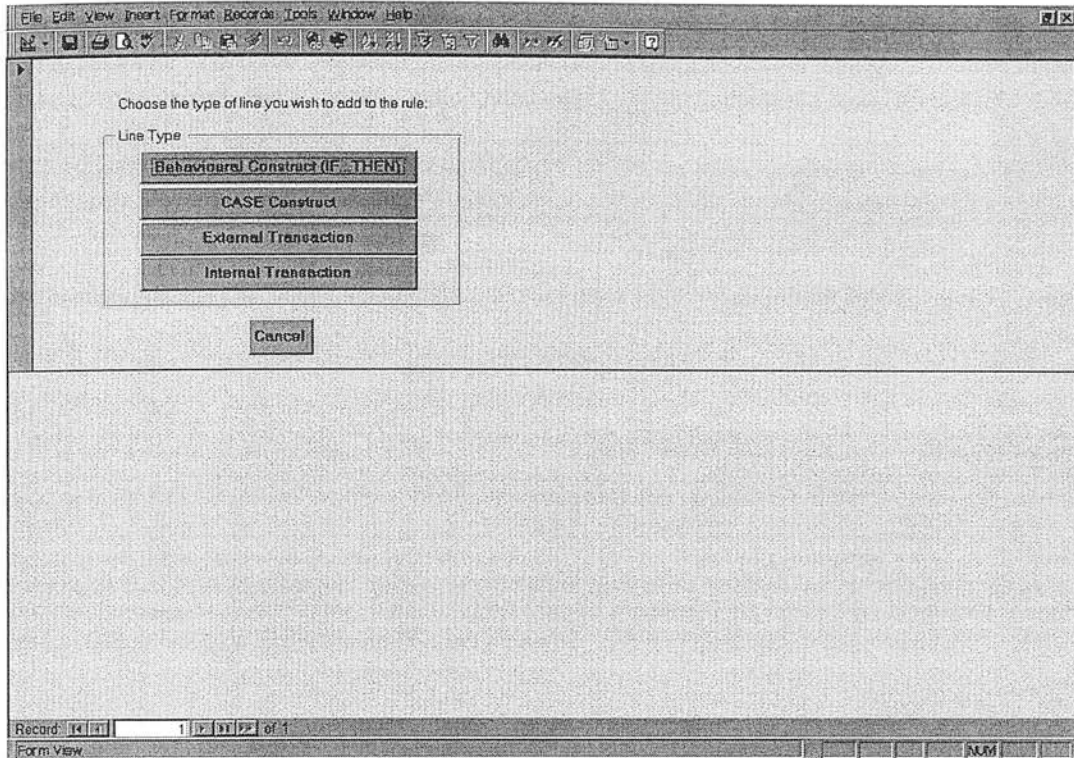


Figure 7.19 Screenshot of the line types available within each rule.

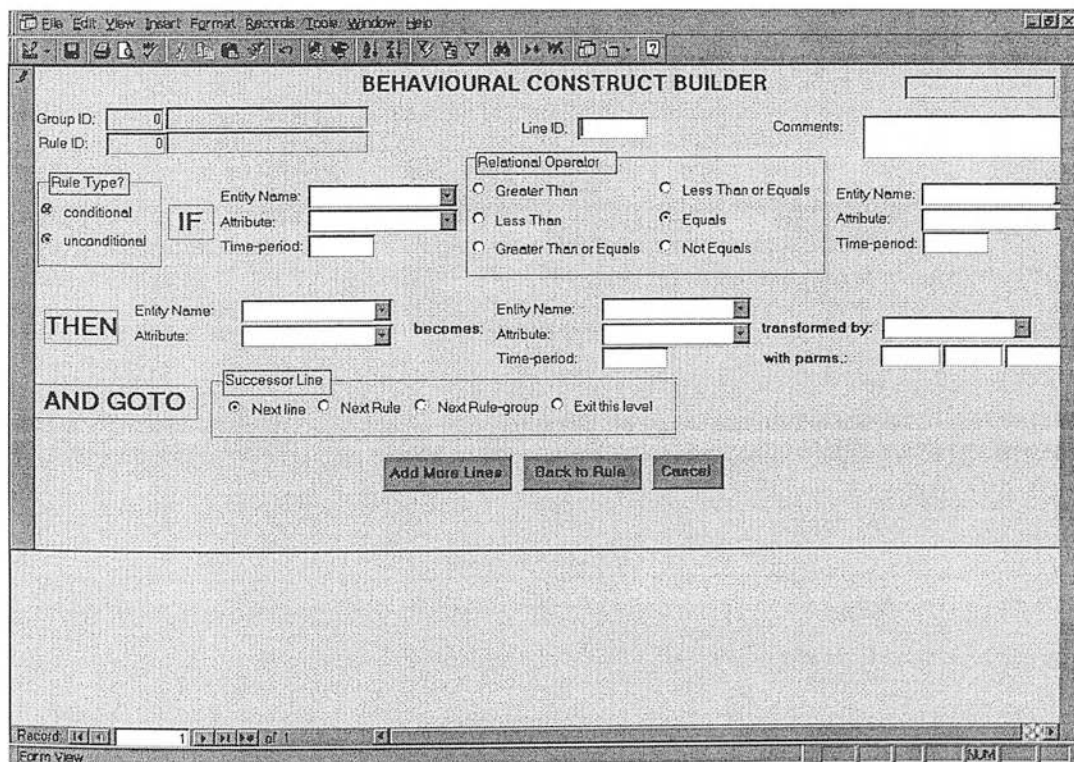


Figure 7.20 Screenshot of a 'behavioural construct' line

CASE STATEMENT BUILDER

Group ID: Rule ID: Line ID: Comments:

Assign result to VAR ☐

If this condition is satisfied... **...assign this value as the result**

Entity Name: Attribute:

Record: 14 of 1

Otherwise, the result is:

Add More Lines **Back to Rule** **Cancel**

Record: 14 of 1

Form View

Figure 7.21 Screenshot of a 'case statement' line

INTERNAL TRANSACTION BUILDER

Group ID: Rule ID: Line ID: Comments:

CONVERT

Entity: Attr: no. of units:

TO

Entity: Attr:

with Kg Maize equiv.: and Process Efficiency:

AND GOTO

Successor Line

☐ Next line ☐ Next Rule ☐ Next Rule-group ☐ Exit this level

Add More Lines **Back to Rule** **Cancel**

Record: 14 of 1

Form View

Figure 7.22 Screenshot of an 'internal transaction' line.

EXTERNAL TRANSACTION BUILDER

Group ID: Rule ID: Line ID: Comments:

COMMODITY

SELLER Entity Name: Attribute:

↓

quantity:

↓

BUYER Entity Name: Attribute:

CASH

Entity Name: Attribute:

↑

quantity:

↑

AND GOTO Successor Line ☒ Next line ☐ Next Rule ☐ Next Rule-group ☐ Exit this level

Add More Lines Back to Rule Cancel

Record: 1 of 1 Form View

Figure 7.23 Screenshot of an ‘external transaction’ line.

A user starts the rule input or maintenance process by selecting the ‘Maintain Rules’ option on the opening screen of the user interface (see Figure 7.13 in section 7.5.2). This will transfer users to the screen shown in Figure 7.16. The user can maintain an existing rule group; move, copy or delete one or more rule groups; or, add a new rule group. Where the user is inputting rules for the first time, the last option is selected and a selection screen is displayed (Figure 7.17) to gather the principal parameters about the rule group. The user must provide a rule group name, the level in the hierarchy to which the rule group is attached and the processing sequence in relation to the hierarchical processing and the sequence of other rule groups. If the user then opts to ‘Add Rules’, the screen in Figure 7.18 is displayed. Here, the user is required to provide a rule name and to indicate the sequence of the rule execution in relation to other, existing rules, within the rule group. The user is now at the lowest level of the rule structure and, if entering rules, will select ‘Add Lines’, displaying the screen in Figure 7.19. At this point, the user must select the type of line that is required. There are four types available and these are as follows:

- **Behavioural Construct** – this is essentially the classic ‘IF...THEN...ELSE’ statement, where the user enters variables (either field references from the population database or temporary variables from earlier lines of the rule) and single actions are initiated (Figure 7.20).
- **Case Statement** – similar to the latter type, but allowing multiple conditions and outcomes (Figure 7.21).
- **Internal Transaction** – transfers from the *Crops* to the *Food* table, converting units to kilocalories via an intermediate maize standard equivalent weight (Figure 7.22).
- **External Transaction** – sales between one level of the hierarchy and another, requiring matching of quantities and cash in the tables of both entities (Figure 7.23).

The above screenshots are samples of the thirty five different screens included within the editor for input and maintenance of rules. After a user completes the input and maintenance, the rules are ‘validated’ against the population database and the list of temporary variables. This validation process is more akin to a checking procedure than a model validation. Its purpose is to ensure that rules will execute when the simulation is initiated, rather than cause a program ‘crash’ as a result of logic or referencing errors.

(An example of a rule group for input is enclosed in Appendix IX. This shows the detailed rule logic for Household-level Rule Group 5 – Transfer of Food Crops. See section 7.4.1 for the summary description of this rule group.)

7.7 Output, calibration and validation

As the framework has not yet been implemented as a working model (see ‘Remarks’ below), the output module and the procedures for calibration and validation of rule groups and the overall models have not been specified in detail. The broad design issues were covered in the previous chapter in section 6.10. and no further comments on these matters are made herein.

7.8 Remarks

At the time of writing, the second framework has been designed in detail (with the exception of the output module) as described herein. The framework has been constructed by the author and others in accordance with this design, but has not yet been implemented as a working model.

Implementation requires additional work from others within the collaborative research project to formulate and input all rule groups necessary to create the first working model from the framework.

As designed and constructed, this framework offers advantages compared to the earlier systems dynamic approach:

- The **explicit recognition of the hierarchical structure** of the socio-economy and the greater integration of the links between the food access and the health/nutrition components are better representations of the food system at community and household level.
- **Short term factors are now represented by separate modules** within the overall layout of the framework, rather than tightly included within, or coupled to, specific sub-models.
- There is **clear separation within this framework between data and experiment**. From a user standpoint, the inclusion of a facility to describe relationships using a pre-defined rule layout aids the modelling process and ensures consistency of modelling approach between users.

In summary, with these advantages, the design and construction of the second framework substantially meets the fourth objective, namely: *‘To provide a modelling framework that will enable users to represent household and community resources and the short-term external factors’*.

However, although the previous chapter laid the basis of a design for the output procedures and validation methods, there has been no detailed design and construction for these matters. Therefore, it can only be concluded that this second framework partially meets the fifth objective, viz: *'To include, within the modelling framework, suitable methods of providing output data, about changes in nutritional status, which are sufficient for comparison with independently derived data to confirm or otherwise the coherent representation of the processes.'*

8 Discussion

8.1 Purpose

As a wide ranging discussion of design considerations has already been reported in chapter 6, it will not be repeated in these closing remarks. The purpose of this final chapter therefore is to discuss the extent to which the objectives set for the PhD have been attained. To show this, the various strengths and weaknesses of each section of the work will be summarised together with its contribution to meeting the objectives. Future developments of the framework and to the simulation of food systems will be discussed and an overall conclusion will be made.

Throughout the thesis the author has necessarily had to include references to work by other members of the collaborative research project and these contributions are fully recognised as set out in the acknowledgements. It may be appropriate to restate that the author himself has been responsible for the overall design of the modelling framework, but not for the individual sub-models that will be incorporated therein. These have been the responsibility of others and in several cases have not yet been completed. Without the completion of these sub-models, the validation of the framework design can only be limited to 'face validity' (Oakshott, 1997) at this time.

8.2 Strengths and weaknesses

In assessing the strengths of the work overall, the matters covered in each of the previous chapters (other than the introduction) provide a suitable checklist:

8.2.1 Literature review

♦ Strengths

This provided a comprehensive and balanced review of the differing perspectives of food security in general and the modelling of malnutrition for the purposes of food aid targetting. Of particular note are the recently reported works of Ellis (2000), Scoones (1998) and Carney (1998) concerning a 'livelihoods' approach to the analysis of rural development issues. These references were included retrospectively in the review and

thus postdate much of the research reported in this thesis. However, it is encouraging to observe that the ideas inherent in the different types of capital embodied in the livelihoods approach and its holistic view of rural households' activities, have some similarities with the frameworks developed herein. Other authors' findings relating to temporal and spatial variability were reported in the context of the discussions about seasonality. It was observed that economic views of food shortages, in particular those of Sen, played down the role of infection and disease in famine related mortality. Various existing modelling applications' methods of analysis and reporting of malnutrition at different scales: regions, countries, districts, communities and households were reviewed. It was noted that these applications rarely address the hierarchical structure of the underlying socio-economic environment in which food systems operate nor are they inherently dynamic in their approaches, focussing only on one point in the future. The livelihoods approach referred to above implicitly recognises this hierarchical socio-environment (particularly through the idea of 'social capital'). However, other than the reported work of Smith and Strauss (1986) and recent unpublished work by Nkowan (1997) and Nhantumbo (1997), there has been limited attention paid to how such structures should be represented, especially within the context of dynamic modelling. Three possible approaches to simulation modelling were reviewed and their merits compared briefly.

♦ Weaknesses

Although the review examines the various approaches to modelling food security *per se*, there is little coverage of the importance of the modelling of the *data* associated therewith. In particular, more literature should have been identified about the simulation of rainfall at local scale and over short time periods (meteorological models that use secondary data should have been reviewed); the simulation of illness by cohort over time and at local scale (epidemiological models should have been reviewed); and the extrapolation of population data from a mixture of primary and secondary data. One area omitted from the review is the importance of gender within household decision making and both frameworks reflect this weakness by assuming that all household assets are used for the benefit of all household members (this is discussed further in section 8.2.6 below). Surprisingly perhaps, this weakness seems to be shared with the authors of the works on 'livelihoods approach', all of whom give

scant attention to the recognition of the gender specificity in ownership of assets. Ellis (2000) limits his observations (p.156) to the gender bias in ownership of land and access to credit. Scoones' working paper (1998) makes only a single reference to gender (p.8), suggesting that it is simply one 'dimension of difference', along with wealth, age etc. Carney (1998b), in her introductory section 'Implementing the sustainable livelihoods approach' makes no mention whatsoever of 'gender' and omits its consideration from the guidance on the pentagonal analysis of capital assets (p.8). (It seems to this author that an interesting extension of their work would be to examine the use of dual (assuming a monogamous household) pentagons and their interaction for assessing capital assets and so capture the realities associated with gender differentiation.) The implications for future work to extend the modelling framework to incorporate gender are discussed in section 8.2.6 below.

8.2.2 Household survey

♦ Strengths

The overall approach to the household survey was well founded. The design of the sample frame was well executed and although the selected sample wards presented problems for the researchers in terms of access thereto, the subsequent cluster analyses carried out suggested that they were broadly representative. Data collection methods were generally adequate. Data were collated within an overall scheme that gave the individual researchers a central source from which to access information for their own analysis and model development, whilst appreciating the links to other disciplines. This must be an important consideration when implementing a modelling framework that requires collaboration. The analysis of the household survey data, for identification of temporal and spatial dependency, was most useful in providing an overview of the importance across all factors influencing nutritional status. Additional data analysis in response to comments has provided better insight into the gender differences in anthropometry and the zonal differences in infants' and children's nutritional status.

◆ Weaknesses

Too many data were collected about matters that were not germane to the development of the simulation model and insufficient data were collected for important areas. Data editing in the field was poor and numerous errors resulted in substantial work being required to 'clean' the data in the months following the survey. Excessive data collected related to anthropometry, detailed agricultural practices and food consumption. Insufficient data were collected about rainfall, income and expenditure and grain trading (including prices). For this work (and, indeed, the collaborative research project) it would have been preferable to have started with a basic framework design and then determined the data requirements. Although hindsight may be influencing this criticism, future implementations of the framework should certainly be planned in this way.

8.2.3 Secondary data sources

◆ Strengths

The secondary data provide good coverage of many of the factors associated with the processes causing malnutrition. The collection of these data and, more importantly their collation, underlines the richness of such sources in developing countries and their general under-utilisation. Although the 'Index of Infrastructural Vulnerability' was not pursued, it may offer a potentially low-cost and speedy analysis of many of the factors. The decision to use a G.I.S. for store and analyse these data was appropriate and enabled researchers to relate their analyses to the spatial referencing of the modelling framework.

◆ Weaknesses

The difficulties of obtaining secondary data were grossly under-estimated. Not only was this the case for the census data, but the other data tended to be jealously guarded by their 'owners'. For future implementations of this framework, in other parts of Zimbabwe or other countries, a preliminary inventory of such data and potential access problems is recommended. The quality of secondary data was over-estimated. On several occasions, data were provided which had been wrongly collected, were

unchecked for trivial errors or contained errors of such magnitude that they clearly had not even been reviewed prior to issue. This suggests the need to carry out a systems analysis or limited audit of those reporting channels and processes that provide data to future implementations of the framework.

8.2.4 Framework I – a systems dynamic approach

♦ Strengths

This chapter represented the principal conceptualisation of the framework, albeit that the choice of modelling methodology was subsequently changed. The decomposition of the vague UNICEF diagram, into the constituent food access and health/nutrition components and, in turn, to their sub-components was a significant milestone. Breaking down the overall process into discrete sub-processes, largely homogeneous in discipline, enabled the individual researchers within the collaborative project to focus more easily on their own areas of responsibility, but relate their contribution to the development of an overall representation. Although the systems dynamic framework was discarded, it provided a useful ‘testbed’ to experiment with linking the various sub-processes to see whether plausible behaviour could be modelled over an agricultural year.

♦ Weaknesses

On reflection, it is clear that systems dynamic methodology, as implemented by the various software available, was unsuited to modelling spatial variability and multiple heterogeneous objects such as households. Perhaps this should have been foreseen, but until the extent of these two issues became apparent, the explicit *system* modelling approach (with strong temporal control and use by others in economic and biological models) had clear attractions. From the outset, the author and colleagues from the collaborative research project would refer to *flows*, of food, people and other resources, implicitly perceiving the food system as a *continuous process*, analogous to a biological or ecological system, wherein systems dynamic methodology had its roots. But, it is clear now from the detailed deconstruction of the majority of processes involved in resource change that they are occurring in response to *discrete*

events and are not continuous. Thus discrete event simulation is likely to offer a better correspondence to food system behaviour than continuous simulation.

8.2.5 Further design considerations

◆ Strengths

The grain trading behaviour identified by Vaze and others emphasised the need for an explicit hierarchical structure, but prior to this point it was unclear how transactions could be modelled within such a representation. Vaze's optimal control model of two region grain trading provided the theoretical support to the author's own (more laboured) analysis. His model enables dynamic pricing to be easily incorporated within the modelling framework (after modification for the dual external market prices of the G.M.B.) and the other data requirements of the price function are consistent with the framework design. The discussion in this chapter of the problems of simulating 'matched bargains' led to the eventual development of the C.I.A.O. concept and this was the second significant milestone in the work. It enabled a discrete event design, with a hierarchy and with heterogeneous households, to be advanced. Other issues resolved in this chapter: rule based modelling, separation of data from experiment and the need for 'data generators' for rainfall and disease were also of significant importance to the second framework design.

◆ Weaknesses

Although the C.I.A.O. idea was a strong influence on the overall design of the second framework, it remains an untested concept. Ideally, the idea should have been simulated in isolation, using Vaze's model embedded within it, before inclusion in the final design. However, the limitations of household data relating to grain trading and pricing has been noted above. Without such data, any simulation could not be adequately tested and its validity would be difficult to assess. Nonetheless, this must remain a concern and in further work will need close examination. Tentatively, the use of it within the context of the Zimbabwean pricing system would seem to be acceptable. This is because the G.M.B. supports the prices of the principal crops throughout the season and effectively the prices within the modelled district are constrained by exogenous factors. However, if Zimbabwe moves away from this

price support regime or the framework is implemented in other countries where there is a free market, its validity would be questionable and a separate simulation of the C.I.A.O. idea would then be essential prior to use.

8.2.6 Framework II – an expert systems simulation

♦ Strengths

The second design is a thorough exposition of the accumulated ideas developed in the previous chapters. Furthermore, the framework has not been left solely in the design stage, but has been constructed by the author and others to a state where it can be used to implement working models, through the input of user-developed behavioural rules. The detailed presentation of the population database – both its structure and the method developed for extrapolating the quasi-sample – is a substantial achievement. Similarly, the rule base design offers a very flexible tool for users that is both easy to use and ensures a standard structure to the individual sub-models created by different users. The diagrams of the interactions between rules, the population database and the short term factors for each level of the hierarchy provide an excellent conceptual template for this framework and for future developments. There is clear separation between *experiment* and *data* and this enables simulations to be controlled in such a way that the results from multiple runs can easily be obtained for statistical analysis. The author initiated the development of the rainfall ‘generator’ used in the second framework and contributed to the methodology used. This will have uses beyond the current work in other applications requiring simulated rainfall at local scale.

♦ Weaknesses

Although the second framework is a very substantial improvement compared to the first, systems dynamic design, there are seven clear weaknesses:

- **Gender** – the framework treats the household as a single system, with no gender differentiation about the control of resources. There is an increasing amount of evidence of men and women owning and/or controlling different income producing assets within the household and therefore exercising expenditure control over the cash received. From work done by the author and

others in another area of Zimbabwe (Mutisi et al. 1998) women have control of small livestock (chicken and goats) and also the gardens close by the house. Both these activities produce a steady stream of cash (cf. the 'lumpy' profile of crop production income) which is applied directly to household food and other essential purchases. Men, by comparison, control the crop production, cattle and are usually the earners of off-farm income. Their cash stream is more uneven and will be spent with different priorities to those of the women. The extent to which this gender differentiation compromises the validity of the framework is difficult to gauge. It might be possible to modify the second framework and split the household resources between male and female components, with the associated decision making being coded as separate rule bases. This would not prevent some decisions being made for the benefit of the household as a whole or for the benefit of specific dependent cohorts e.g. children. Such a gender split is however, a major expansion of the scope of the modelling framework and would require substantial design and detailed sub-model development.

- **Excessive rules** – although the rule base offers users the flexibility to control all aspects of their implemented models, it could be argued that there is too much flexibility. That is to say that many of the processes which comprise the rule groups described should perhaps be standardised, as they will operate in essentially the same way in most locations e.g. crop growth, food purchases. These standard rules would be parameterised and users would then adjust the rules to suit their implementation. The users would retain the ability to add their own rules to the standard collection.
- **Livestock** – due to lack or poor quality of data collected during the household survey and with similar problems in the secondary data, the framework represents livestock with simple categories of ownership and associated net income. For communities with limited livestock keeping households this may be appropriate, but in the southern areas of Zimbabwe and in other countries this activity can predominate the household income and needs to be represented more comprehensively.
- **Off farm income** – similarly to livestock, the data collected for off-farm income are sparse and this has limited its representation to a small number of

categories. Where such income forms a higher proportion of the household cash inflows, it will be necessary to expand the analysis in both the population database table and the rule base.

- **Incomplete framework** - The second framework requires additional input from collaborators in the research team to complete their sub-models and input the necessary rules. This task is not trivial and reflects the noted bullet point above that the number of rules required to implement any sub-model is substantial.
- **Validation** – Because the framework is incomplete and no full scale models have been implemented, validation has been limited to Oakshott's (1997) 'face validity.' As the completion of the framework and the implementation of models are uncertain due to time and financial constraints, full validation is unlikely to occur in the short term.
- **Computing capacity** – Whilst prototypes of the very limited models have been implemented on a desktop personal computer, the execution speed is noticeably slow. This may be related to the programming or software used, but is more likely to be caused by the excessive number of rules. This problem will be exacerbated when full-scale models are executed using a population database with circa 4,000 households (i.e. a 10% sample). As it is intended that multiple simulations will be performed in order to permit statistical analysis of the results (given that some of the modelled processes are stochastic in nature), the planned use of desktop personal computers may not be feasible. If this occurs, the use of the model in less developed countries will be compromised.

8.3 *Suggestions for further work*

In the short term the second framework needs to be implemented by expert users (cf. inexperienced users) from the collaborative research project to enable a working model to be tested for 'face validity' and subsequently assumption / parameter testing of the individual rule groups and the overall implemented model. When these first two validation stages have been completed and any shortcomings have been corrected, the output modules can be designed in detail and incorporated within the framework. Assuming this is successful, a series of different models should be implemented and multiple simulations executed to enable statistical comparisons to be made with the

limited malnutrition data available from growth monitoring clinics and morbidity statistics for Buhera District.

As noted in section 1.2, it was not the objective of the work to design a modelling framework that was replicable throughout Zimbabwe or easily adaptable for use in other countries. Rather, the design was intended to be modifiable and transferable to similar areas within Zimbabwe. Thus, upon conclusion of the validation stages and the statistical assessment of the results of multiple simulations using data for the Buhera District, the model should be evaluated using data from other rural Zimbabwean districts exhibiting similarities to the conditions in Buhera. If such similar districts can be modelled successfully, it will be possible to assess whether the design can be extended to other, less similar districts in Zimbabwe and other countries in the region.

One area related to the implementation of the C.I.A.O. concept that should be carefully considered is the treatment of stocks held by central traders. Currently, the framework as designed and constructed assumes a nil stockholding by all traders at the end of each time step i.e. there is complete market clearing every dekad. This is clearly unrealistic and traders will hold inter-period stocks. The framework should therefore be modified to include trader stockholdings and various sensitivity analyses performed to establish the effects of different stock levels upon the system. With no stocks and therefore full market clearing, the system will be very responsive, with grain moving quickly from areas of surplus to those of deficit (assuming the households therein have cash to purchase). If fixed stockholdings are introduced, the traders will in effect act as buffers to these grain movements and the response of the system will be smoothed. A further modification would be to use upper and lower stock limits for traders – variable buffers – which would have the effect of smoothing the system's response still further.

Following this, the models should be re-run and then subjected to close scrutiny by more general users for a detailed evaluation of input procedures, user interfaces and output, correcting any shortcomings thereafter. Assuming this is completed successfully, the framework should be treated a working prototype and funding

sought to develop a distributable version with full documentation that can be used by government and N.G.O.s in the field.

As noted above, the framework relies on Vaze's model of inter-regional trading to establish prices. This model examines the role of an external market and Vaze shows that this is the principal determinant of prices in rural markets. In Zimbabwe, post-liberalisation, the G.M.B. plays just such a role and thus his model fits well with the overall framework design and particularly with the C.I.A.O. concept. However, for countries where no parastatal intervenes in the market with a price support mechanism like that provided by the G.M.B., the framework and the implicit approach to pricing, using Vaze's model, will need revision.

In the future, an appropriate research project would be to extend the simulation period from one year to multiple years and consider the impact of changing the variables that are at present included within the framework as 'static'. Had this been undertaken within the context of the current project, it would have required the field survey work to extend across multiple years, which budgetary resources did not permit. With a multi-year simulation, inter-seasonal comparison and longer term trends could then be explored against the background of changes in rural infrastructure.

The retrospective review of additional literature (specifically the recently published work on 'livelihoods approach') carried out in response to comments made on the submitted draft of the thesis has suggested an alternative direction for the further work. The author has recognised that there are similarities in this approach to the work reported herein. In particular, the integrated analysis of household assets and income sources fits well with the ideas embodied in the framework. It would be possible to alter the asset structure used in the formulation of the population database within the framework (see section 7.3) to use the five asset categories of physical, financial, human, natural and social capital defined by the livelihoods approach. The indicators used by Scoones (1998) and Ashley and Carney (1999) to measure these assets could form the detail of the data tables representing each asset category. This would enable the processes by which assets are mediated by household (and higher level) activities to be implemented as a series of rules in much the same way as reported herein. With a standardised approach to assets and indicators, the main rules

could be formulated by experts from the various organisations implementing livelihoods analysis in their programmes (see Carney, 1999a) and additional, local rules appended as appropriate. Such an approach would reduce considerably the complexity of the models, within the capacity of personal computers, so allowing implementation in less developed countries. As a final note of caution, however, the omission of explicit recognition of gender within the framework would not be solved by such an approach (as the livelihoods approach is also deficient in this respect). However, on the basis that any development along such lines would require input from workers in the livelihoods area (e.g. Ellis, Scoones and Carney), the problem could at least be shared and addressed jointly.

8.4 Attainment of objectives

The detailed objectives set out in chapter 1 and the extent to which these have been met, as shown in parentheses, are:

1. To establish that methodologies for nutritional, physiological and micro-economic analyses of subsistence farming communities are well documented or can be developed and are suitable for inter-related use (**achieved**).
2. To obtain, either by field survey or from secondary sources, sufficient data to characterise adequately household and community resources and analyse the effects of external factors (**achieved, with some shortcomings**).
3. To develop methods for inter-relating the analyses, within a modelling framework, to support the coherent representation of the processes underlying the food system (**achieved**).
4. To provide a modelling framework that will enable users to represent household and community resources and the short-term external factors (**achieved, but not yet fully validated**).
5. To include, within the modelling framework, suitable methods of providing output data, about changes in nutritional status, which are sufficient for comparison with independently derived data to confirm or otherwise the coherent representation of the processes (**partially achieved as output module has not yet been designed in detail**).

The overall objective of the work is: *'To design a framework that can be used to build a simulation model of the local food system to forecast spatial and temporal variability in nutritional status of inhabitants of a rural community in Zimbabwe'*.

Given that most of the detailed objectives have been met in full and the remainder substantially achieved, this overall objective for the work can be considered to have been attained.

8.5 Conclusion

The work has demonstrated that it is feasible to design and construct a modelling framework to implement dynamic simulation models of food systems in developing countries. Further work is required to implement working models and so validate the framework. The methodology needs to be converted from a research project to a working tool for users in government, N.G.O.s and other researchers. Multi-year models are feasible development of the work herein. The use of such simulations allows the temporal variability of food access and health to be modelled both intra-seasonally and inter-seasonally. Intra-seasonal results will provide a decision support tool for targetting of food aid and health interventions. Inter-seasonal simulations will offer guidance to policymakers as to the comparative effectiveness of inter-sectoral resource allocation and rural development policies in alleviating malnutrition.

The alternative direction for further work suggested in section 8.3 above offers a route which should overcome some of the shortcomings discussed. Such a route has the added advantage that the conceptual ideas embodied in the work herein would be restructured to be more consistent with the livelihoods approach to rural development analysis that is gaining acceptance amongst researchers, NGO's and other donors. Given the comments in Carney (1998a), Chapter 9 (see section 2.3), such a route may attract support from the Department for International Development and other funding bodies.

References

- A.C.C./S.C.N. (1991). Some options for improving nutrition in the 90's. *SCN News* 7, A.C.C./S.C.N., United Nations, Geneva, Switzerland.
- A.C.C./S.C.N. (1997). *Nutrition and Poverty. Papers from the A.C.C./S.C.N. 24th Session Symposium. A.C.C./S.C.N. 24th Session Symposium, Katmandu, March 1997.* Nutrition Policy Paper #16, A.C.C./S.C.N., United Nations, Geneva, Switzerland.
- A.C.C./S.C.N. (1987). *First Report on the World Nutrition Situation.* A.C.C./S.C.N., United Nations, Geneva, Switzerland.
- Adelman, I., Taylor, J. E. and Vogel, S.. (1988). "Life in a Mexican village: a S.A.M. perspective." *Journal of Development Studies* 25: 5-24.
- Aitkin, M. Anderson, D. and Hinde, J (1981). Statistical modeling of data on teaching styles. *Journal of the Royal Statistical Society, Series A.* 144 (4): 419-461.
- Alderman, H., Chiappori, P. A., Haddad, L., Hoddinott, J. and Kanbur, R.. (1995). "Unitary Versus Collective Models of the Household: Is it Time to Shift the Burden of Proof?" *The World Bank Research Observer* 10(1): 1-19.
- Aron, J. L. and May, R. M. (1996). The population dynamics of malaria. *Infections Disease Dynamics*: 139-179.
- Ashley, C. and Carney, D. (1999). *Sustainable livelihoods: lessons from early experience*, London, Department for International Development.
- Baber, R. (1998). *The structure of livelihoods in South Africa's Bantustans: Evidence from two settlements in Northern Province*, unpublished doctoral thesis, Magdalen College, Oxford.
- Becker, G. (1965). A theory of the allocation of time. *Economic Journal* 75: 493-517.
- Bendokat, R. and Tovo, M. (1999). A social protection strategy for Togo. *SP Discussion Paper 9920, Human Development Network, Social Protection Unit, World Bank.* Washington D.C., The World Bank.
- Boius, H. E. (1983). "Seasonal rice price variation in the Philippines: Measuring the effects of government intervention." *Food Research Institute Studies* 19(1): 81-92.
- Booch (1994). *Object-oriented analysis and design with applications.* 2nd edition. Benjamin/Cummings, Redwood City, California, U.S.A..

- Borton, J. and Shoham, J. (1989). Experiences of non-governmental organizations in the targeting of emergency food aid. A report on a 'workshop on Emergency Food Aid Targeting' at the London School of Hygiene and Tropical Medicine, London 4-6th January 1989. *Disasters* 13: 77-93.
- Borton, J. and Shoham J. (1991). *Mapping Vulnerability to Food Insecurity: Tentative Guidelines for WFP Offices*. Relief and Development Institute, London.
- Bright, G. (1999). Assessing the effects of hazards and interventions on farm household liquidity in Sudan – a preliminary accounting model. *Journal of Agricultural Economics* 50 (1): 83-92
- Bryk, A. and Raudenbush, S. (1992). *Hierarchical linear models*. Newbury Park, California USA, Sage Publications Inc.
- Buchanan-Smith, M. and Davies, S. (1995) *Famine early warning and response, the missing link*. Intermediate Publications, London.
- Buchanan-Smith, M., Davies, S. and Lambert, R. (1991). *A guide to famine early warning and food information systems in the Sahel and Horn of Africa*. Research Report No. 21, Institute of Development Studies, University of Sussex, Brighton,
- Bush, R. (1985). "Briefings: Drought and Famines." *Review of African Political Economy*, 33 61-62.
- Carney, D. (Ed.) (1998a). *Implementing the sustainable livelihoods approach: what contribution can we make?* London, Department for International Development.
- Carney, D. (1998b). Implementing the sustainable livelihoods approach, Chapter 1 in Carney, D. (ed.) *Implementing the sustainable livelihoods approach: what contribution can we make?* London, Department for International Development.
- Carney, D. (ed.) (1999a). *Livelihoods approaches compared*, London, Department for International Development.
- Carney, D. (1999b). Approaches to sustainable livelihoods for the rural poor, *ODI Poverty Briefing*, London, Overseas Development Institute.
- Carraro, L. (1996). *Understanding famine: a theoretical dynamic model*. Development Studies Working Paper No. 94, Centro Studi Luca d'Agiano, Terion, Italy.

- Casti, J. (1997). *Would be worlds: how simulation is changing the frontiers of science*. John Wiley & Sons Inc, New York , U.S.A..
- Chambers, R. (1989). Editorial introduction: vulnerability, coping and policy. *IDS Bulletin* 2(2): 1-7.
- Chambers, R., Longhurst, R. and Pacey, A.. (1981). *Seasonal dimensions to rural poverty*. Frances Pinter, London.
- Clarke G.M. and Cooke D. (1998). *A basic course in statistics*. London, Arnold.
- Corbett, J. (1988). Famine and household coping strategies. *World Development* 16(9): 1099-1112.
- Corbett, J. (1994). *Livelihoods, food security and nutrition in a drought prone part of Zimbabwe*. ESCOR report no. R4685, Centre For the Study of African Economies, University of Oxford, Oxford.
- Crow, B. (1986). *US policies in Bangladesh: the making and the breaking of famine?* Development Policy and Practice: Working Paper No. 4, The Open University, Milton Keynes.
- Currey, B. (1993). *Bangladesh: Vulnerable Rural Households (1983-84)*. Shomabesh Institute, Dhaka, Bangladesh,
- Cutler, P. (1984a). Famine forecasting: Prices and peasant behaviour in Northern Ethiopia. *Disasters* 8(1): 48-56.
- Cutler, P. (1984b). Food crisis detection: going beyond the balance sheet. *Food Policy* 9(3): 189-192.
- Cutler, P. (1985). Detecting food emergencies - Lessons from the 1979 Bangladesh Crisis. *Food Policy* 10(3): 207-224.
- d'Amato M. (1999). *Cut off points for nutritional status classification by age cohorts and sex* . Personal communication.
- da Corta, L. (1986) *The persistence of famine: a dynamic approach combining entitlement and peasant mobility theories in the analysis of vulnerability to famine*. Preliminary draft of a DPhil thesis, St. Antony's College, University of Oxford, quoted in Devereux (1993) (p.81) - see below.
- Daley, C.L., Carceres, C.F., Choi, K.H., Hearst, N., Hironaka, K., Osmond, D.H. (1998) *International Epidemiology of HIV/AIDS*. The AIDS Knowledge Base. Published on the internet at: <http://hivinsite.ucsf.edu/akb/1997/01epiint/>
- Dasgupta, P. (1993). *An Inquiry into Well-being and Destitution*. Oxford University Press, Oxford.

- Davies, S., Buchanan-Smith, M. and Lambert, R. (1991). *Early warning in the Sahel and Horn of Africa: the state of the art*. Research Report No. 20, Institute of Development Studies, Brighton, England.
- Davies, S. (1993). Are coping strategies a cop out? *IDS Bulletin* 24: 60-72.
- Davies, S., Buchanan-Smith, M. and Lambert, R.. (1991). *Early Warning in the Sahel and Horn of Africa: The State of the Art. A Review of the Literature*. Brighton, U.K., University of Sussex, Institute of Development Studies.
- de Janvry, A., Fafchamps, M. and Sadoulet, E.. (1991). Peasant household behaviour with missing markets: some paradoxes explained. *Economic Journal* 101: 1400-1417.
- de Waal, A. (1990) A re-assessment of entitlement theory in the light of recent famines in Africa. *Development and Change* 21: 469-490
- de Walt, K. M. (1983). Income and dietary adequacy in an agricultural community. *Social Science Medicine* 17: 1877-86.
- Delgado, C. (1986). A variance components approach to food grain market integration northern Nigeria. *American Journal of Agricultural Economics* 68(4).
- Devereux, S. (1988). Entitlements, availability and famine. A revisionist view of Wollo, 1972-74. *Food Policy* 13: 270-282.
- Devereux, S. (1993). *Theories of famine*. Harvester Wheatsheaf, Hemel Hempstead.
- Devereux, S. (2000). *Famine in the Twentieth Century*. IDS Working Paper No. 105. Institute of Development Studies, University of Sussex, Brighton.
- Downing, T. E. (1990). *Assessing Socio-economic Vulnerability to Famine: Frameworks, Concepts, and Applications*. Washington, D.C., USA, USAID, Famine Early Warning System Project.
- Drèze, J. and Sen A. (1989). *Hunger and Public Action*. Oxford University Press, Oxford.
- Durkin, J. (1994). *Expert systems – design and development*. Prentice Hall, New Jersey, U.S.A..
- Dusauchoit, T. (1994). *MSF-CIS (Celula Inter-Seccoes), Mozambique: a data collecting system focused on food security and population movements*. ODI Relief and Rehabilitation Network Paper No. 2, Overseas Development Institute, London.
- Dyson, J.R. (1997) *Accounting for non-accounting students, 4th Edition*. Pitman Publishing, London.

- Ellis, F. (1988). *Peasant Economics. Farm households and agrarian development*, Cambridge, Cambridge University Press.
- Ellis, F. (1992). *Agricultural policies in Developing Countries*, Cambridge, Cambridge University Press.
- Ellis, F. (2000). *Rural Livelihoods and Diversity in Developing Countries*, Oxford, Oxford University Press.
- Epstein, J. and Axtell, R. (1996). *Growing artificial societies: social science from the bottom up*. Washington DC USA, Brookings Institution / MIT Press.
- Ferro-Luzzi, A., Pastore, G. and Choto, R.. (1992). *Strategies Within the Household to Meet Seasonal Food Shortage: a Study in 3 Developing Countries on Energy-Sparing Metabolism - Zimbabwe Case Study*. STD II Final Scientific Report. Rome, National Institute of Nutrition.
- Ferro-Luzzi, A., Branca, F. and Pastore, G.. (1994). Body Mass Index Defines the Risk of Seasonal Energy Stress in the Third World. *European Journal of Clinical Nutrition* 48(3).
- Food and Agriculture Organisation of the United Nations (1997). *Summary Report: Second informal meeting on methodology for vulnerability assessment, December 9-10, 1996*. Reference ES:GCP/INT/535/EEC Technical Report, F.A.O. Rome, Italy.
- Food and Agriculture Organisation of the United Nations (1997b). *Report on the F.A.O./W.H.O. expert consultation on carbohydrates in human nutrition, Rome, 14-18 April 1997*. F.A.O. Nutrition paper #66, F.A.O. Rome, Italy.
- Frankenberger, T. R. (1992). Indicators and Data Collection Methods for Assessing Household Food Security .In Maxwell S. and Frankenberger T. R. *Household Food Security: Concepts, Indicators, Measurements*. UNICEF/IFAD, New York, USA,. 73-134.
- Gilbert, N. and Conte, R (eds.) (1995). *Artificial societies: the computer simulation of social life*. UCL Press, London. .
- Gillespie, S. and Mason, J. (1991). *Nutrition-Relevant Actions - Some Experiences from the Eighties and Lessons for the Nineties*. State-of-the-Art Series Nutrition Policy Discussion Papers, A.C.C./S.C.N., United Nations, Geneva, Switzerland.

- Goldman, R. H. (1974). Seasonal rice prices in Indonesia, 1953-69: An anticipatory price analysis. *Food Research Institute Studies in Agricultural Economics, Trade and Development* 13(2): 99-143.
- Goldstein, H. (1995). *Multilevel statistical models*. London, Arnold.
- Government of Zimbabwe (1984). *Zimbabwe: 1:1,000,000 natural regions and farming areas, 2nd edition*. Department of the Surveyor-General, Government of Zimbabwe, Harare.
- Government of Zimbabwe. (1988). *Primary health care / Maternal and child health / expanded programme on immunisation surveys*. Ministry of Health, Government of Zimbabwe, Harare, Zimbabwe.
- Government of Zimbabwe (1994): *Census 1992 - Manicaland Provincial Profile*. Central Statistics Office, Harare.
- Government of Zimbabwe (1995a). *Monthly rainfall data for meteorological stations in Zimbabwe*. Government of Zimbabwe, Meteorological Office, Harare.
- Government of Zimbabwe (1995b) *Agricultural Production in Communal Lands 1985-93*. Ministry of Lands, Agriculture and Water Development, Government of Zimbabwe, Harare.
- Gundry, S.W. and Ferro-Luzzi, A. (1994): *An integrated model of the food system in a region of Zimbabwe. Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Scientific progress report to DGXII of the European Commission, for the period 1 February 1993 to 31 January 1994*. Unpublished. Issued Edinburgh July 1994, pp 67.
- Gundry, S.W. and Ferro-Luzzi, A. (1995): *An integrated model of the food system in a region of Zimbabwe. Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Scientific progress report to DGXII of the European Commission, for the period 1 February 1994 to 31 January 1995*. Unpublished. Issued Edinburgh July 1994, pp 51.
- Gundry, S.W. and Ferro-Luzzi, A. (1996): *An integrated model of the food system in a region of Zimbabwe. Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Scientific progress report to DGXII of the European Commission, for the period 1 February 1995 to 31 January 1996*. Unpublished. Issued Edinburgh March 1996, pp 193.
- Gundry, S.W., Ferro-Luzzi, A. and Wright J.W. (1997): *An integrated model of the food system in a region of Zimbabwe. Science and Technology for Developing*

- Countries Programme (Contract reference: TS3*-CT92-0048) Scientific progress report to DGXII of the European Commission, for the period 1 February 1996 to 31 January 1997.* Unpublished. Issued Edinburgh June 1997, pp 156.
- Gundry, S.W., Wright, J.A. and Ferro-Luzzi, A. (2000): *An integrated model of the food system in a region of Zimbabwe. Science and Technology for Developing Countries Programme (Contract reference: TS3*-CT92-0048) Final report to DGXII of the European Commission.* Unpublished. Issued Edinburgh February 2000, pp147.
- Gundry, S.W., Wright, J.A. and Ferro-Luzzi, A. (1998) The use of a rule-base to simulate the food and nutrition system in a rural Zimbabwe. Paper presented at 4th World Congress on Expert Systems, March 16-20 1998, Mexico City, Mexico and published in the proceedings (Volume 1): Cantu, F., Soto, R., Liebowitz, J. and Sucar, E. (eds.), Cognizant Communication Corporation, New York, U.S.A, 301-308.
- Gundry, S.W., Wright, J.A., Austin, E. and Worrall, E.J. (1999) Populating a Simulation Model of the Food System in Zimbabwe with Representative Household Data. Paper presented at ModSim 99, the International Congress on Modelling and Simulation, University of Waikato, New Zealand. 6-9 December 1999. Published in the proceedings: Oxley, L., Scrimgeour, F. and McAleer, M. (eds), ISBN 0-86422-949-6. The Modelling and Simulation Society of Australia and New Zealand Inc., 1999. Vol 2, pp343-348.
- Haddad, L. (1994). "Strengthening food policy through intrahousehold analysis." *Food Policy* 19 (4): 347-356.
- Haddad, L. Hoddinott, J. and Alderman, H. (eds.) (1997). *Intrahousehold resource allocation in developing countries. Models, methods and policy.* International Food Policy Research Institute, Johns Hopkins University Press, Maryland U.S.A.
- Haggblade, S., Hazell, P. and Brown, J. (1989). Farm-Nonfarm linkages in rural sub-Saharan Africa, *World Development*, Vol 17, 8, 361-374.
- Hannon, B. and Ruth, M. (1994). *Dynamic Modeling.* New York, Springer-Verlag.
- Hay, R.W. (1986). The political economy of famine. *Nutritional Health* 4: 71-82.
- Holzmann, R. and Jorgensen, S. (1999). Social protection as social risk management: conceptual underpinnings for social protection sector strategy paper. *SP*

- Discussion Paper 9904, Human Development Network, Social Protection Unit, World Bank.* Washington D.C., The World Bank.
- Holzmann, R. and Jorgensen, S. (1999). Social risk management: a new conceptual framework for social protection and beyond. *SP Discussion Paper 0006, Human Development Network, Social Protection Unit, World Bank.* Washington D.C., The World Bank.
- Horton, S. (1988). Birth order and child nutritional status: evidence from the Philippines. *Economic Development and Cultural Change* 36: 341-354.
- Houghton J.T., Meira Filho L.G., Bruce J., Hoesung Lee, Callander B.A., Haites E., Harris N. and Maskell K., (1995). *Climate Change 1994: radiative forcing of climate change and an evaluation of the IPCC IS92 emission scenarios.* Cambridge University Press on behalf of the Intergovernmental Panel on Climate Change.
- Howells, O., Edwards-Jones, G. and Morgan, O. (1998) Ecozone II: a decision support system for aiding environmental impact assessments in agriculture and rural development projects in developing countries, *Computers and Electronics in Agriculture*, Vol. 20, 2, pp. 145-164.
- Hutchinson, C. F. (1991). Uses of satellite data for famine early warning in sub-Saharan Africa. *International Journal of Remote Sensing* 12(6): 1405-1421.
- Jackson, P. (1999). *Introduction to Expert Systems. Third Edition.* Harlow, Addison Wesley Longman.
- Jayne, T. S. (1994). Do High Food Marketing Costs Constrain Cash Crop Production? Evidence from Zimbabwe. *Economic Development & Cultural Change* 42(2): 387-402.
- Jayne, T. S. and Chisvo, M. (1991). *Zimbabwe's Food Insecurity Paradox: Implications for Grain Market Reform in Southern Africa.* Harare, Department of Agricultural Economics and Extension, University of Zimbabwe.
- Joy, L. (1973). Food and Nutrition Planning. *Journal of American Economics* XXIV(January 1973).
- Kambarami, R.A., Nathoo, K.J., Nkrumah, F.K. and Pirie, D.J.. (1991) Measles epidemic in Harare, Zimbabwe, despite high measles immunization coverage rates. *Bulletin of the World Health Organization.* 69(2): 213-9.
- Kennedy, E. and Peters, P. E. (1992). *Household food security and child nutrition: the interaction of income and gender of household head.* Development Discussion

- Paper Harvard Institute for International Development No. 417, 21pp.; 13 r: 21pp.
- Lambert, R., Gershon, M., Buchanan-Smith, M. and Davies, S. (1991). *Famine early warning and food information systems in the Sahel and Horn of Africa: an annotated bibliography*. Development Bibliographies No. 7, Institute of Development Studies, Brighton, England.
- Lambert, R. J. (1994). Monitoring local food security and coping strategies: lessons from information collection and analysis in Mopti, Mali. *Disasters* 18: 332-343.
- Langton, C.G. (1995). *Artificial life: an overview*. MIT Press, Cambridge, Massachusetts, U.S.A..
- Law, A.M. and Kelton, W.D. (1991) *Simulation modelling and analysis, 2nd edition*. McGraw-Hill Inc. USA.
- Lawrence, M., Lawrence, F., Cole, T.J., Coward, W.A., Singh, J. and Whitehead, R.G.. (1989). Seasonal Pattern of Activity and Its Nutritional Consequence in Gambia. In Sahn, D (ed.) *Seasonal variability in Third World agriculture : the consequences for food security*. IFPRI/Johns Hopkins University Press, Baltimore, Maryland USA, 47-56.
- Leftwich, A. and Harvie, D. (1986) *The political economy of famine*. Discussion paper 116. Institute for Research in the Social Sciences, University of York, York.
- Lindskog, U., Lindskog, P., Carstensen, J., Larsson, Y. and Gebre-Medhin, M.. (1988). Childhood mortality in relation to nutritional status and water supply - a prospective study from rural Malawi. *Acta Paediatrica Scandinavica* 77(2): 260-268.
- Longhurst, R. (1986). Household food strategies in response to seasonality and famine. *IDS Bulletin* 17: 27-35.
- Macro International Inc., Ministry of Health and University of Zimbabwe. (1996). *Nutrition and health status of young children and their mothers in Zimbabwe*. Report for United States Agency for International Development, Office of Health and Nutrition under The Food Security and Nutrition Monitoring Project (IMPACT), Contract No. DAN-5110-Q-00-0014-00. Macro International Inc., Calverton, Maryland, U.S.A.

- Maxwell, D. (1996). Measuring food insecurity: the frequency and severity of coping strategies. *Food Policy*, Volume 21 (3) 291-303.
- Maxwell, S. (1996). Food security: a post-modern perspective. *Food Policy*, Volume 21 (2) 155-170.
- Maxwell, S. and Frankenberger, T. R. (1992). *Household Food Security: Concepts, Indicators, Measurement. A Technical Review*. New York, UNICEF and IFAD.
- Maxwell, S. and Smith, M. (1992). Household Food Security: A Conceptual Review. In Maxwell S. and Frankenberger T.R. *Household Food Security: Concepts, Indicators, Measurements. A Technical Review*. New York, UNICEF/IFAD: 1-72.
- Mazur, R. and Sanders, D. (1988). Socio-economic factors associated with child health and nutrition in peri-urban Zimbabwe. *Ecology of Food and Nutrition* 22: 19-34.
- Mendoza, G. and Prabhu, R. (2000). Multiple criteria decision making approaches to assessing forest sustainability using criteria and indicators: a case study. *Forest Ecology and Management*, Vol. 131 pp. 107-126.
- Messer, E. (1989). Seasonality in Food Systems: An Anthropological Perspective on Household Food Security. In Sahn D. (ed.). *Seasonal variability in Third World agriculture : the consequences for food security*. Baltimore, Maryland USA, IFPRI/Johns Hopkins University Press: 151-176.
- Moy, R.J.D., Booth, I.W., Choto, R.G., McNeish, A.S. (1991). Early Growth Faltering in Rural Zimbabwean Children. *Central African Journal of Medicine* 37: 275-281.
- Moyo, S. (1995). The Land Question in Zimbabwe. Harare, SAPES Trust.
- Mutisi C., Younger C., Illius A., Gundry S.W. and Kusina N. (1998): Perception of production and service values for livestock in semi-arid subsistence farming systems. Poster paper presented at the *British Society for Animal Science Meeting: 'Food, Lands and Livelihoods', Nairobi, Kenya. 27-30 January 1998*.
- Naylor, T.H and Finger, J.M. (1967) Verification of computer simulation models. *Management Science*, (14) pp 92-101.
- Nhantumbo, I. (1997) *Multiobjective rural land use planning: : potential for social forestry in Maputo, Mozambique*, unpublished doctoral thesis, University of Edinburgh.

- Nkowan, K. (1997) *Modelling land/resource-use of options open to smallholder farmers in the Northern Region of Zambia : a multiple objective programming approach*, unpublished doctoral thesis, University of Edinburgh.
- Oakshott, L. (1997). *Business modelling and simulation*. London, Pitman.
- Oglethorpe, D. R. (1995). Sensitivity of farm plans under risk-averse behaviour: a note on the environmental implications. *Journal of Agricultural Economics*. 46: 227-232.
- Payne, P. (1989). Public Health and Functional Consequences of Seasonal Hunger and Malnutrition. In Sahn, D. *Seasonal variability in Third World agriculture : the consequences for food security* IFPRI/Johns Hopkins University Press, Baltimore, Maryland USA, 19-46.
- Payne, P. and Lipton, M. (1994). *Agricultural Development and Nutrition*. Hutchinson, by arrangement with FAO and UNICEF.
- Peters, E. P. and Herrera M. G. (1994). Tobacco cultivation, food production and nutrition among smallholders in Malawi. In von Braun J. and Kennedy. E. (eds.) *Agricultural commercialisation, economic development and nutrition*. Baltimore, Maryland USA, IFPRI/Johns Hopkins University Press: pp 309-327.
- Railsback, S. and Land, M. (1999) A salmon migrant model using SWARM. Oral presentation at *SWARM Developers Conference, March, 1999, University of California at Los Angeles, U.S.A.*
- Ralston, K. (1996). Household nutrition and economic linkages: a village social accounting matrix for West Java, Indonesia. In Taylor J. E. and Adelman I. *Village economies : the design. estimation. and use of villagewide economic models*. Cambridge University Press, Cambridge. 146-181.
- Rasmussen, S. and Barrett C. (1995). *Elements of a theory of simulation*. Santa Fe Institute Working Papers 95-04-040. Santa Fe Institute, New Mexico, U.S.A..
- Ravallion, M. (1986), Testing market integration, *American Journal of Agricultural Economics*, 68, 102-109.
- Ravallion, M. (1986). Testing market integration, *American Journal of Agricultural Economics*, 68, 102-109.
- Ravallion, M. (1987), *Markets and Famines*. Oxford, Oxford University Press.
- Ravallion, M. (1996). Famines and Economics, *Policy Research Working Paper 1693*. Washington D.C., The World Bank.

- Reardon, T. (1997). Using evidence of household income diversification to inform study of the rural nonfarm labor market in Africa, *World Development*, Vol. 25, 5, pp. 735-747.
- Rosenzweig, M. R. and Wolpin, K. I. (1982). Governmental interventions and household behaviour in a developing country. *Journal of Development Economics* 10: 209-225.
- Roth M., (1990) Analysis of agrarian structure and land use patterns in Zimbabwe. Paper prepared for *World Bank Agriculture Sector Memorandum*, World Bank, Washington, U.S.A..
- Rukuni, M. and Jayne, T.S. (1995). Alleviating hunger in Zimbabwe: towards a national food security strategy. Supplement to *Zambezia, the Journal of the University of Zimbabwe*, University of Zimbabwe Publications, Harare, Zimbabwe.
- Sahn, D. E. (1989). 'A conceptual framework for examining the seasonal aspects of household food security'. In Sahn, D. E. (ed) *Seasonal variability in third world agriculture: the consequences for food security*, IFPRI/Johns Hopkins University Press.
- Sahn, D. E. and Delgado C. (1989). The Nature and Implications for Market Interventions of Seasonal Food Price Variability. In Sahn D. (ed.) *Seasonal variability in Third World agriculture : the consequences for food security*. IFPRI/Johns Hopkins University Press, Baltimore, Maryland USA, 179-195.
- Sahn, D. (1994). The impact of macroeconomic adjustment on incomes, health and nutrition: sub-Saharan Africa in the 1980's, Chapter 13 in Cornia, G. and Helleiner, G. (eds.), *From Adjustment to Development in Africa: Conflict, Controversy, Convergence, Consensus?*, London, Macmillan pp. 273-297.
- Schlesinger, S. (1974). Developing standard procedures for simulation, validation and verification. *Proceedings of the 1974 Summer Computer Simulation Conference*. pp 927-933
- Scoones, I. (1994). *A Hazardous Existence: Farming Livelihoods in Dryland Zimbabwe. Coping with Uncertainty in Africa's Drylands*. London, IIED.
- Scoones, I. (1998). Sustainable rural livelihoods: a framework for analysis, *IDS Working Paper No 72*, Brighton, Institute of Development Studies.
- Scrimshaw, N. S. and Taylor, C. E. (1968). *Interactions of Nutrition and Infection*. Geneva, World Health Organisation.

- Seaman, J., Holt, J. and Allen, P. (1993). *A New Approach to Vulnerability Mapping for Areas at Risk of Food Crisis*. Save The Children Fund, London.
- Sen, A. K. (1977). Starvation and exchange entitlements: a general approach and its application to the great Bengal famine. *Cambridge Journal of Economics* 1.
- Sen, A. K. (1981). *Poverty and Famines: An Essay on Entitlement and Deprivation*. New York, Oxford University Press.
- Sen, A. K. (1988). *WIDER research for action. Hunger and entitlements*. World Institute, Finland, pp38.
- Senauer, B. (1990). Household behaviour and nutrition in developing countries. *Food Policy* 15: 408-417.
- Shoham, J. and Clay, E. (1989). The role of socio-economic data in food needs assessment and monitoring. *Disasters* 13: 44-60.
- Shortiffe, E. and Buchanan, B.G. (1975). A model of inexact reasoning in medicine. *Mathematical Biosciences* 23: 351-379.
- Siegel, P. and Alwang, J. (1999). An asset-based approach to social risk management: a conceptual framework. *SP Discussion Paper 9926, Human Development Network, Social Protection Unit, World Bank*. Washington D.C., The World Bank.
- Singh, I., Squire, L. and Strauss, J. (eds.) (1986a). *Agricultural household models. Extensions, applications and policy*. Baltimore, Johns Hopkins University Press.
- Singh, I., Squire, L. and Strauss, J. (1986b). The Basic Model: Theory, empirical results and policy conclusions. Chapter 1 in Singh, I., Squire, L. and Strauss, J. (eds.) *Agricultural household models. Extensions, applications and policy*. Baltimore, Johns Hopkins University Press.
- Smith, V. and Strauss, J. (1986). Simulating the rural economy in a subsistence environment: Sierra Leone. Chapter 7 in Singh, I., Squire, L. and Strauss, J. (eds.) *Agricultural household models. Extensions, applications and policy*. Baltimore, Johns Hopkins University Press.
- Staatz, J. M., D'Agostino, V. C. and Sundberg, S.. (1990). Measuring food security in Africa: conceptual, empirical, and policy issues. *American Journal of Agricultural Economics* 72: 1311-1317.

- Stone, J. R. N. (1978). The disaggregation of the household sector in the national accounts. Paper presented at the *World Bank conference on Social Accounting Methods in Development Planning*, April 16-21, 1978, Cambridge.
- Tagwireyi, J. and Greiner T. (1994). *Nutrition in Zimbabwe: an update*. The World Bank, Washington D.C., U.S.A..
- Takayama, T. and Judge, G. G. (1971) *Spatial and Temporal Price and Allocation Models*, North Holland, Amsterdam.
- Taylor, J. and Adelmann I. (1996). *Village economies: the design, estimation and use of villagewide economic models*. Cambridge University Press, Cambridge.
- Taylor, J. E. (1995). *Micro economywide models for migration and policy analysis: an application to Mexico*. Organization for Economic Cooperation and Development, Paris, France.
- Thomas, D. (1997). Incomes, expenditures and health outcomes: evidence on intrahousehold resource allocation, in Haddad, L. Hoddinott, J. and Alderman, H. (eds.) (1997). *Intrahousehold resource allocation in developing countries. Models, methods and policy*. International Food Policy Research Institute, Johns Hopkins University Press, Maryland U.S.A. pp.142-164.
- Tomkins, A., Watson, F., Scrimshaw, N.S.. (1989). *Malnutrition and Infection: A Review*. State-of-the-art series, A.C.C./S.C.N., United Nations.
- Tripp, R. B. (1982). Farmers and traders: Some Economic Determinants of Nutritional Status in Northern Ghana. *Food and Nutrition* 8.
- UNICEF (1990). *Strategy for Improved Nutrition of Children and Women in Developing Countries*. New York, UNICEF Policy Review.
- UNICEF (1991). *Children and Women in Zimbabwe: A Situation Analysis Update - July 1985 - July 1990*. UNICEF Zimbabwe, Harare, Zimbabwe.
- United Nations (1998). *Revision of World Population Estimates and Projections*. United Nations Population Division, Department of Economic and Social Affairs. Published on the internet at: <http://www.popin.org/pop1998/6.htm>
- U.S.A.I.D.(1992). *Towards the Development of a Methodology for Food Aid Targeting in Zimbabwe*. U.S.A.I.D., Famine Early Warning System, Harare, Zimbabwe.
- Valentine, T. R. (1993). Drought, Transfer Entitlements, and Income Distribution: The Botswana Experience. *World Development* 21(1): 109-126.

- Vaze, P.B., Kudhlande, S., Wright, J. and Gundry, S.W. (1996a): A spatial analysis of household grain purchases in Zimbabwe's liberalised marketing system. *Outlook on Agriculture* 25 (1): 37-42
- Vaze, P.B., Mudimu, G., Gundry, S.W. and Wright, J.A. (1996b). Dynamics of Grain Stocks in Rural Zimbabwe. *Development Studies Association 1996 Annual Conference, University of Reading 18-20 September 1996*, pp 15.
- Vaze P.B. (1999). *A model of inter-regional trade and storage of grain: an application to Zimbabwe and Tanzania*. PhD Thesis, Department of Economics, University of Edinburgh.
- von Braun, J. and Pandya-Lorch, R. (eds.) (1991). *Income sources of malnourished people in rural areas: microlevel information and policy implications*, Working Papers on Commercialisation of Agriculture and Nutrition No. 5, Washington D.C., International Food Policy Research Institute.
- von Braun, J. and Kennedy, E. (eds.) (1994). *Agricultural commercialisation, economic development and nutrition*. Baltimore, Maryland USA, IFPRI/Johns Hopkins University Press.
- von Braun, J., Tesfaye, T. and Webb P. (1999). *Famine in Africa. Causes, responses and prevention*. Baltimore, Maryland USA, IFPRI/Johns Hopkins University Press.
- Webb, P., Richardson, E., Seyoum, S. and Yohannes, Y. (1995). *Vulnerability mapping and geographical targeting: an exploratory methodology applied to Ethiopia*. Report to the United States Agency for International Development, Health and Human Resources Analysis for Africa Project PIO/T 698-0483-3-3613025 by International Food Policy Research Institute, Washington D.C., U.S.A.
- Williams, M.D., Hollan, J.D. and Stevens, A.L. (1983). *Human reasoning about a physical system*. In Genter, D. and Stevens, A. (eds.) Erlbaum, New Jersey, U.S.A. 131-153.
- Winston, W. (1995). *Introduction to mathematical programming. Applications and algorithms*. Belmont, California, Duxbury Press.
- Working, H. (1958). A theory of anticipatory prices. *American Economic Review* 48(2): 188-199.
- World Bank (1986). *Poverty and Hunger: Issues and Options for Food Security in Developing Countries*. Washington D.C., World Bank.

- World Bank (1989). *Sub-Saharan Africa: From Crisis to Sustainable Growth - A Long-Term Perspective Study*. Washington D.C., The International Bank for Reconstruction and Development/The World Bank.
- World Bank (1999). *Africa region social protection sector strategy paper*, Mimeo, Southern Africa Department, World Bank, Washington D.C., World Bank.
- Wright, J.A., Gundry, S.W., Ferro-Luzzi, A., Hoyles, P.J., Vaze, P.B., Nyatsanza, J. and Dent, J.B.(1998): Identifying the temporal and spatial trends in growth monitoring data and the links to socio-economic and environmental variability in Zimbabwe. *Ecology of Food and Nutrition* 37: 247-267.
- Wright, J. A. (1998). *Information Systems for Child Nutrition in Zimbabwe*. PhD Thesis. Faculty of Science and Engineering, University of Edinburgh.
- Wright, J.A., Smith, J., Gundry, S.W., Glasbey, C. (1999) Spatial simulation of rainfall data for crop production modelling in southern Africa. Paper presented at *ModSim 99, the International Congress on Modelling and Simulation, University of Waikato, New Zealand. 6-9 December 1999. Published in the proceedings: Oxley, L., Scrimgeour, F. and McAleer, M. (eds), ISBN 0-86422-949-6. The Modelling and Simulation Society of Australia and New Zealand Inc., 1999. Vol 4, pp1069-1074.*
- Wu, J and Loucks, L.L. (1995). From the balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. *Quarterly Review of Biology* 70 (4): 439-466.
- Wuensche, A. and Lesser, M. (1992). *The global dynamics of cellular automata*. Addison-Wesley, U.S.A..
- Yanagisako, S. (1979). Family and household: the analysis of domestic groups. *Annual Review of Anthropology* 8: 161-205.

Appendix I:

**Technical annex to contract with the European Commission
for the collaborative research project, 1992**

AS sent to EC 20/10/92 and
approved by Calagzere 21/10/92

An Integrated Model of the Food Supply System in a Region of Zimbabwe

STD3 Project 0067 : TECHNICAL ANNEX

1. Introduction

The project will construct and test an integrated model of the food supply system in Urungwe, for an area of about 2,000 sq kms, located within the Mashonaland West region of Zimbabwe. The objectives are:

- i) To provide a comprehensive view of the operation of the food system at household, village and regional level.
- ii) To analyse the food flows between these levels and identify the flows to individuals (at the micro level) and nationally (at the macro level).
- iii) To incorporate the effects of seasonal patterns of production, distribution and consumption into the model and so facilitate dynamic forecasting of key indicators of nutritional status.
- iv) To identify the public structures (either government or international agencies) which monitor, control or otherwise intervene in the food supply system.
- v) To evaluate the model as a decision support system for use in food aid planning. *PK*
- vi) To identify local units able to use the model and decision support system.

The model will be developed using 'IDRISI', the geographic information system adopted by FAO for use in developing countries as part of the Global Information and Early Warning System (GIEWS) workstation project. This link to the FAO project will facilitate the model's evaluation and subsequent use on a more widespread basis.

2. Work Plan

Each phase will comprise of a number of research tasks, all of which will be carried out by the participating institutions:

- University of Edinburgh, Scotland ('Edinburgh')
- National Institute of Nutrition, Rome, Italy ('Rome')
- University of Zimbabwe, Harare ('Zimbabwe')
- University of Eduardo Mondlane, Maputo ('Mozambique')

2.1 Data Collection and analysis

2.1.1 Sample selection

The region of study is the catchment area for the Magunje grain

marketing warehouse, which forms part of the nationwide network operated by the parastatal Grain Marketing Board (GMB). This area comprises about 2,000 sq kms of communal lands with a population of about 40,000 people. Villages consist of small groups of huts (usually between 5 and 30) with each household having about 3 Ha of cultivated land, not necessarily adjacent to the hut, but usually close to the village.

The quality of maps for the region is good with population data based on surveys in 1982, with the 1992 census results expected shortly. These should therefore provide an acceptable basis from which to select a sample. It is anticipated that with a 5% sample, between 300 and 400 households will be selected for study, but the final number will depend on the methods adopted for stratification by household characteristic and income.

Responsibility: Edinburgh
Assisted by: Zimbabwe/Mozambique

2.1.2 Household membership and resources

Each sample household will be interviewed in depth to ascertain membership (including those working away), cash income and health record - these last two data are likely to be unreliable and care will be needed in formulating the questionnaire to gain a comprehensive picture.

In addition, the questionnaire will record the resources of the household including land, animals, buildings, tools and savings (if any). The crops grown, including seed type, will also be recorded together with the farmer's use of fertilisers and hired labour.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.1.3 Anthropometric measurement of nutritional status

At three key seasons in the year: pre-harvest, post harvest and pre-planting, the nutritional status of each household will be determined by anthropometric measurement. These measurements will be carried out on all family members and will provide the basis for estimating the household's nutritional requirements, by comparison with WHO standards.

Responsibility: Rome
Assisted by: Zimbabwe/Mozambique

2.1.4 Consumption and dietary preferences

The FAO country nutrition survey for Zimbabwe indicates that cereals contribute 63% of the total calorie supply, with the remainder coming from sugar and honey (13%), fats (7%), animal products (4%) and vegetables (1%). It is expected that a substantial variance from these figures will be seen for the poorer, rural households.

Using the sample selected in section 2.1.1, the total consumption of each household will be ascertained on a regular basis during the year. No attempt will be made to disaggregate each individual's consumption

of family-produced crops, but dietary preferences and external (to the household) consumption will be surveyed on an individual basis. Estimates of discretionary consumption over basic subsistence will be made for each household. The nutritional content of each commodity will be estimated by reference to standard composition tables.

Responsibility: Zimbabwe
Assisted by: Mozambique/ Rome

2.1.5 Crop production - ground based survey

Maize is the principal staple. Other crops grown by subsistence farmers are groundnuts, soya beans and seasonal vegetables. Production statistics for maize and these other crops will be collected by visit and interview during May - June 1993, the harvest season. Production of non-seasonal supplementary crops grown on vegetable plots will also be monitored during the year.

Long term data for crop yields, correlated to climate, land quality, seed type, farm size are available and will be used to predict maize harvest yields for comparison with survey data.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.1.6 Post harvest losses

The main staple, maize, is stored by householders without de-husking in cribs, or shelled in granaries, until required for family consumption. Estimates will be made at several stages during the year to assess the reductions occurring in nutritional value through storage, handling and other processing.

Responsibility: Zimbabwe
Assisted by: Mozambique/Rome

2.1.7 Onward flow of produce

Following the harvest of the main staples at the sample households, the onward distribution of the crops will be determined by close monitoring and interview. Whilst some studies indicate that the majority of the crop is retained for family consumption and seed, other research suggests that about 70% of the production is sold either for cash or in exchange for labour in the planting season.

(This section of the survey will provide the key to understanding the operation of the food system at household level. It is hypothesised that in subsistence households a relatively 'closed' system operates, with only a small interaction with the external food system - see enclosure 2.)

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.1.8 GMB operations

Within the region, GMB is the only large scale purchaser (and, to a much lesser extent, seller) of grain, although there are some small scale operations by licensed private traders in the local area. The GMB depot at Magunje stores bagged maize purchased from farmers and from 1993 will store bulk maize in silos, with pest protection measures in place. Post harvest losses in GMB storage have already been analysed by Zimbabwe, but these results will be confirmed by sample and technical analysis.

The depot's operations will be comprehensively reviewed and all transactions - purchases, sales and inter depot transfers - will be recorded and compared to the household flows identified.

Responsibility: Zimbabwe
Assisted by: Edinburgh/Mozambique

2.1.9 Other traders and minor commodity suppliers

Other small grain traders and suppliers of supplementary commodities into the region will be monitored by visiting the local markets and shops in the main towns nearby. Volumes, prices and seasonality of supplies will be recorded.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.2 National food system and public structures

2.2.1 GMB national network

The network of grain marketing warehouses and regional/central bulk storage facilities will be identified and documented, together with summary transaction data for maize for previous years. The links to import and export grain movements, together with total volumes of maize shipped will also be identified and recorded. The links to the Magunje GMB depot will also be fully analysed.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.2.2 Pricing policies

World and internal maize prices (which are state controlled) since 1980 have been analysed by the University of Zimbabwe. This work shows a correlation between internal prices, which are set at planting time, and production levels in the following season. This data will be incorporated into the model, although care will be needed in using broad national statistics to predict behaviour by small subsistence farming households at local level.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.2.3 Analysis of public structures

The public structures involved within the food system at a national level will be identified and the key factors of influence determined. Where possible, these factors will be incorporated, but comprehensive inclusion of national data will not be possible at this stage, given that the focus of the model is at district level.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.3 **Model Building**

2.3.1 Model design and specification

Before any survey work is undertaken the conceptual framework of the model will be established and the data structures, input formats and output requirements assessed. The basic organisation of the model will accommodate the flows of the principal staples from harvest, through the households into the regional storage and distribution chains and thence to other areas of the country for eventual consumption.

The detailed design specification will be drawn up during planning visits to both Zimbabwe and Rome, to ensure no data redundancy exists and that all research requirements are met. The outline specification will also be discussed with FAO, aid agencies, GMB and Agritex (the Zimbabwe Government department responsible for agricultural technical and extension services).

Responsibility: Edinburgh
Assisted by: Zimbabwe/Mozambique

2.3.2 Model programming

Crucial to the success of the model will be the ability to reflect accurately the spatial nature of production, distribution and consumption. To achieve this, the programming of the model will be implemented on the geographic information system 'IDRISI', which has been adopted by FAO as part of its larger project to provide a common computer workstation for use by developing countries in food management. Use of this GIS will facilitate the integration of maps and numerical survey data, so providing graphic representation of the seasonal food flows.

The programming will be carried out in Edinburgh, but copies of early models will be sent to each partner for evaluation. Initial survey data will be used to test the prototype of the model.

Responsibility: Edinburgh
Assisted by: Zimbabwe/Mozambique

2.3.3 Data input

As the survey data are collected, so they will be input into the model in

Zimbabwe. Because of the large data volumes involved, it is anticipated that extensive use will be made of either computer readable input forms, or laptop microcomputers for data collection in the field.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.4 Field testing

At this point in the programme (early 1994), it is anticipated that a prototype model of the food flows within the region will have been completed. This part of the project will test the validity of the model by running the programs for 1994 crop production data and testing the output against surveyed nutritional status and field data for stored commodities at all points in the food chain. The testing will be based on approximately half the original sample.

2.4.1 Forecast surpluses

From the ground surveys the model will forecast crop production statistics which will enable potential surpluses and shortfalls, by household, to be determined. The onward food flows entering the storage and distribution chain, particularly those to the GMB depot at Magunje, will be predicted. Seasonal fluctuations in levels of grain stored at households and Magunje will thus be estimated. Estimates will be updated during the course of the growing season.

This section of the field testing is one of the main benchmarks of the model and it is anticipated that the findings in the second surveys of distribution and storage will result in modifications to the programs.

Responsibility: Edinburgh
Assisted by: Zimbabwe/Mozambique

2.4.2 Forecast nutritional status

The other main benchmark for the success of the model will be its ability to predict nutritional status of households. Using the same sample as above, the predicted nutritional status for each household will be compared to those derived from a second set of anthropometric measurements, taken at the same three points in the year as in the original survey.

Responsibility: Rome
Assisted by: Zimbabwe/Mozambique

2.4.3 Repeat surveys

As per section 2.1, but with reduced sample of households.

Responsibility: Zimbabwe
Assisted by: Mozambique/Edinburgh

2.4.4 User acceptance of model

After modifying the model to take account of the second year's survey data, additional work will be carried out to facilitate use of the model by non-specialist personnel. At this stage, attention will be given to the ease of use which will be gauged by demonstration of the working system to FAO, aid agencies, GMB and Department of Agriculture representatives.

Responsibility: Edinburgh
Assisted by: Zimbabwe

2.4.5 Identify local users

Following the demonstrations of the model and its evaluation as a decision support tool in 2.3.6 above, local units able to use the model will be identified and invited to a workshop to gauge the potential number of users in Zimbabwe.

Responsibility: Zimbabwe
Assisted by: Edinburgh

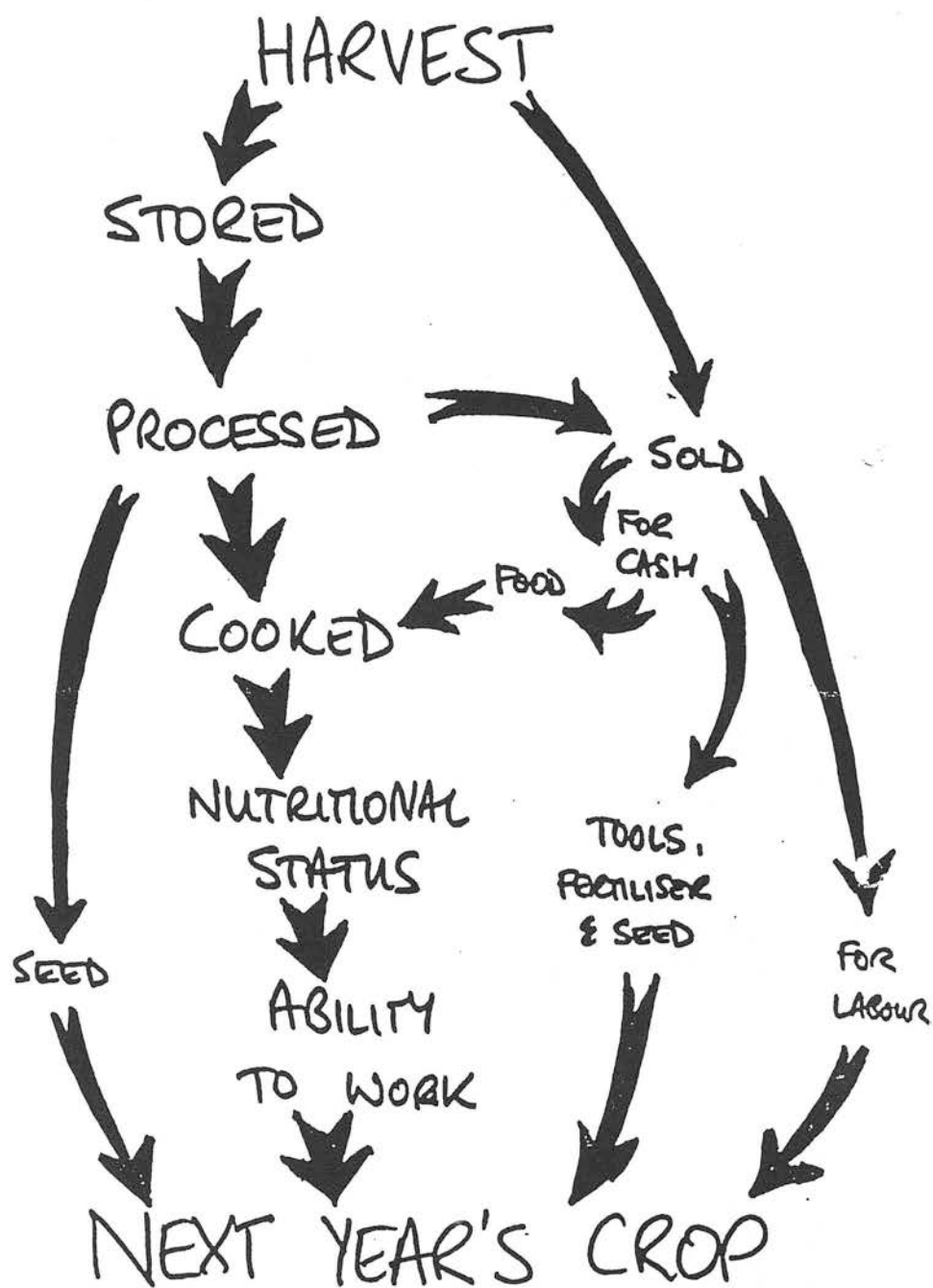
2.4 **Project Management**

Throughout the project, Edinburgh will be responsible for the overall direction of the research work and the coordination of tasks between the collaborating partners. It will also assume responsibility for financial control and monitoring of annual expenditures against budget. Project documentation, including the preparation and submission of interim and final reports to the European Commission and other funding agencies, will also be carried out in Edinburgh.

3. **Future plans**

Further evaluation and field testing will be undertaken during 1995-96 in a region of Mozambique. This will give additional confirmation that the main factors affecting food flows have been correctly understood and incorporated.

20.10.92



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An Integrated Model of the Food Supply System in a Region of Zimbabwe : STD3 Project Ref. 0007 TECHNICAL ANNEX / TASK SCHEDULE

Task Ref.	Description	Partners	1992				1993				1994				1995			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
2.1.	Data collection and analysis																	
2.1.1.	Sample selection	EDI/ZIM/MOZ																
2.1.2.	Household resources	ZIM/MOZ/EDI				***	***	***										
2.1.3.	Anthropometric measurement	ROM/ZIM/MOZ					***	***	***	***	***	***						
2.1.4.	Consumption and diet	ZIM/MOZ/ROM					***	***	***	***	***	***						
2.1.5.	Crop production	ZIM/MOZ/EDI					***	***	***	***	***	***						
2.1.6.	Post harvest losses	ZIM/MOZ/ROM					***	***	***	***	***	***						
2.1.7.	Onward flow of produce	ZIM/MOZ/EDI					***	***	***	***	***	***						
2.1.8.	GMB operations	ZIM/EDI/MOZ					***	***	***	***	***	***						
2.1.9.	Other traders	ZIM/MOZ/EDI					***	***	***	***	***	***						
2.2.	National food system																	
2.2.1.	GMB national network	ZIM/MOZ/EDI									***	***	***					
2.2.2.	Pricing policies	ZIM/MOZ/EDI									***	***	***					
2.2.3.	Public structures	ZIM/MOZ/EDI									***	***	***					
2.3.	Model Building																	
2.3.1.	Design and specification	EDI/ZIM/MOZ				***	***	***	***	***	***	***	***	***	***	***	***	***
2.3.2.	Programming	EDI/ZIM/MOZ						***	***	***	***	***	***	***	***	***	***	***
2.3.3.	Data input	ZIM/MOZ/EDI								***	***	***	***	***	***	***	***	***
2.4.	Field Testing																	
2.4.1.	Forecast surpluses	EDI/ZIM/MOZ											***	***	***	***	***	***
2.4.2.	Forecast nutritional status	ROM/ZIM/MOZ											***	***	***	***	***	***
2.4.3.	Repeat surveys	ZIM/MOZ/EDI											***	***	***	***	***	***
2.4.4.	User acceptance	EDI/ZIM											***	***	***	***	***	***
2.4.5.	Identify local users	ZIM/EDI											***	***	***	***	***	***
2.5.	Project Management	EDI				***	***	***	***	***	***	***	***	***	***	***	***	***

Appendix II:

Agritex Early Warning System crop summary forms for Buhera

CROP FORECASTING SAMPLE SURVEY IN COMMUNAL AREAS OF ZIMBABWE.

SECOND ROUND SURVEY DISTRICT TABULATION SHEET: 18 95/96

PROVINCE MANICALAND DISTRICT BUTHERA

NAME OF OFFICER MUNDEIRI BA

DATE OF COMPIATION 3/4/96

WARD NAME	CROP NAME				CROP NAME			
	STOCKS AVAILABLE IN BAGS	AREA PLANTED THIS YEAR IN HECTARES	EXPECTED PRODUCTION THIS YEAR BAGS/BALES	EXPECTED SALES GMB/COTCO THIS YEAR BAGS/BALES	EXPECTED STOCKS AVAILABLE THIS YEAR BAGS/BALES	AREA PLANTED THIS YEAR IN HECTARES	EXPECTED PRODUCTION THIS YEAR BAGS/BALES	EXPECTED SALES GMB/COTCO THIS YEAR BAGS/BALES
1	960	2572	36160	13920	—	22240	—	—
2	m1	2415	15920	76590	—	39330	—	—
3	1995	525	30450	12600	—	17850	—	—
4	1824	1989	42942	28356	—	14586	—	—
5	3591	2000.7	54207	32661	—	21546	—	—
6	m1	2938	78719	50593	—	29841	—	—
7	m1	3657	58830	13250	—	45580	—	—
8	199563	148357	6652.1	572057	—	152553	3248.7	46.41
9	m1	2295	27900	8100	—	19800	m1	—
10	4655	78204	10613.4	1862	837.9	7913.5	279.3	37.24
11	m1	2927.4	11931	—	1353	10578	—	576.6
12	m1	1007.3	14670	2151.6	—	12578.4	—	440.1
13	925.2	2652.2	48573	10023	555.12	32998.8	—	283.7
14	m1	1580	38125	10125	3125	24875	—	—
15	2539	1027	7949	—	—	7949	—	—
16	1763	827.2	4204	—	—	4204	—	—
17	—	487.3	3773	—	—	3773	—	—
18	—	2694	76314	—	—	76314	—	—
19	2405	2174	44890	24549	—	2142	—	110.2
20	—	1704.3	103455	25047	—	7840.8	—	656.7
21	—	1445.3	14882.4	3005.1	—	18773	—	143.1
22	360	708	6480	2160	480	3840	—	85.2
TOTAL	16227	38345	669194	—	367911	3527	3083	21890

NOTE: Expected Production should EQUAL Expected Sales (GMB/COTCO) + Expected Sales (OTHERS) + Retentions.

DEPARTMENT OF AGRICULTURE
MANICALAND DISTRICT

11 APR 1996

P.O. BOX 113 MUTARE

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[illegible]

NOTE: Expected Production should EQUAL Expected Sales (GMB, COTCO) + Expected Sales (OTHERS) + Retentions..

CROP FORECASTING SAMPLE SURVEY IN COMMUNAL AREAS OF ZIMBABWE.

SECOND ROUND SURVEY DISTRICT TABULATION SHEET: 19 95¹⁰ 96PROVINCE MANICALAND DISTRICT BUTHERANAME OF OFFICER MUNDEIRI B.A.DATE OF COMPIATION 3/4/96

WARD NAME	CROP NAME				CROP NAME				CROP NAME			
	STOCKS AVAILABLE IN BAGS	AREA PLANTED THIS YEAR IN HECTARES	EXPECTED PRODUCTION THIS YEAR BAGS/BALES	EXPECTED SALES GMB, COTCO THIS YEAR BAGS/BALES	EXPECTED SALES OTHERS THIS YEAR BAGS/BALES	EXPECTED STOCKS AVAILABLE BAGS/BALES	AREA PLANTED THIS YEAR IN HECTARES	EXPECTED PRODUCTION THIS YEAR BAGS/BALES	EXPECTED SALES GMB, COTCO THIS YEAR BAGS/BALES	EXPECTED SALES OTHERS THIS YEAR BAGS/BALES	EXPECTED STOCKS AVAILABLE BAGS/BALES	EXPECTED PRODUCTION THIS YEAR BAGS/BALES
1	80	112	1600	—	1600	—	—	—	—	—	—	—
2	—	248	8970	3588	2208	3774	—	—	—	—	—	—
3	—	—	—	—	—	—	—	—	—	—	—	—
4	306	112.2	2040	—	204	1836	—	30.6	408	—	—	408
5	684	51.3	1026	—	—	1026	—	—	—	—	—	—
6	—	137.2	343	—	—	343	—	171.5	1029	—	—	1029
7	—	299.5	5830	—	—	5830	—	1094.5	10600	1325	—	9278
8	3712.8	154.7	773.5	—	—	773.5	—	—	—	—	—	—
9	—	144.9	1350	270	—	1080	—	—	—	—	—	—
10	372.4	131.3	3724	—	1210.3	1955.1	186.2	93.1	186.2	—	837.9	1024.1
11	—	159.9	615	—	—	615	—	639.6	3382.5	—	615	2767.5
12	—	39.12	97.8	—	—	97.8	—	1212.72	1095.6	—	1173.6	9193.2
13	—	1013	8326.8	—	2313	6168	—	104.9	3084	—	616.8	2467.2
14	—	162.5	4000	875	—	4375	—	62.5	750	—	—	750
15	110	88.3	883	—	55.2	331	55.2	97.2	2650	—	—	2650
16	136	40.7	271	—	—	271	814	393.2	1627	—	—	1627
17	—	78.6	629	—	—	629	—	220.1	943	550	—	393
18	—	353.6	1014.3	—	—	1014.3	—	85.1	1690.5	—	—	1690.5
19	—	361	4509	1303	—	3507	—	30.1	2906	1303	—	1603
20	—	69.7	653.4	—	217.8	435.6	—	790.6	7405.2	1197.9	—	6207.3
21	—	372	3434.4	715.5	—	2718.9	—	1144.8	10160.1	4006.8	—	6153.3
22	—	792	4440	—	480	3960	—	1044	7680	480	3720	3480
TOTAL	5400	4845	54527	—	—	36185	1552	9087	5727	—	—	50716

NOTE: Expected Production should EQUAL Expected Sales (GMB, COTCO) + Expected Sales (OTHERS) + Retentions..

[illegible]

NOTE: Expected Production should EQUAL Expected Sales (GMB, COTCO) + Expected Sales (OTHERS) + Retentions..

ZIMBABWE EARLY WARNING UNIT FOR FOOD SECURITY - AGROMETEOROLOGICAL CROP MONITORING & REPORT

Cropping Season: 19 95/96 Province: MATSHANA District: BUTHA BUTHA Report N.: 11 From: 4/3/96 To: 17/3/96

FORM N. 1	PLANTED AREA (Ha)	PLANT. STAGE DEKAD	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANT. STAGE DEKAD	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANT. STAGE DEKAD	COND.	EST. YIELD
Farming Sector												
1 - L.S.C.A.												
2 - S.S.C.A.												
3 - C.A.	28 000	3/10 H	4	1.3	105 000	3/10 H	4	1	32 000	3/10 H	4	0.8
4 - R.A.												
COMMENTS:	Early crop has matured.				COMMENTS:	Crop maturing				COMMENTS:	Crop maturing	
Farming Sector												
1 - L.S.C.A.												
2 - S.S.C.A.												
3 - C.A.	7 000	3/10 H	4	0.7	10 000	3/10 H	4	0.6				
4 - R.A.												
COMMENTS:	Crop maturing				COMMENTS:	Lifting of early crop.				COMMENTS:		
Farming Sector												
1 - L.S.C.A.												
2 - S.S.C.A.												
3 - C.A.												
4 - R.A.												
COMMENTS:					COMMENTS:					COMMENTS:		
Farming Sector												
1 - L.S.C.A.												
2 - S.S.C.A.												
3 - C.A.												
4 - R.A.												
COMMENTS:					COMMENTS:					COMMENTS:		

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DEPARTMENT OF AGRICULTURE
MANICULAND REGISTRY
1.8 MAR 1996
P.O. BOX 143, MUTARE

(0) = Failure, (1) = Very Poor, (2) = Poor, (3) = Fair, (4) = Good, (5) = Very Good

(A) = Planting, (B) = Re-Planting, (C) = Emergence, (D) = Vegetative (Knee Height), (E) = Early Reproductive (Earing), (F) = Reproductive Stage (Flowering), (G) = Grain Development, (H) = Maturity, (I) = Harvest

ZIMBABWE EARLY WARNING UNIT FOR FOOD SECURITY - AGROMETEOROLOGICAL CROP MONITORING & REPORT

Cropping Season: 19 957 96 Province: MANKALANDI District: BUTHLEA Report No.: 11 From: 24/3/96 To: 17/3/96

FORM N. 2	PLANTED AREA (Ha)	PLANT. STAGE DEKAD	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANT. STAGE DEKAD	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANT. STAGE DEKAD	COND.	EST. YIELD
Farming Sector												
1 - L.S.C.A.												
2 - S.S.C.A.												
3 - C.A.	8000	3/10 G	S	0.7	45"	3/10 G	4	1	ml			
4 - R.A.												
	COMMENTS:	Crop doing well			COMMENTS:	Bolls about to mature.			COMMENTS:			
Farming Sector												
1 - L.S.C.A.												
2 - S.S.C.A.												
3 - C.A.	ml				ml				4	3/12 I	4	0.4
4 - R.A.												
	COMMENTS:				COMMENTS:				COMMENTS:	Curing of first pile in progress.		
CROP STAGE												
CROP CONDITION												
(A) = Planting, (B) = Re-Planting, (C) = Emergence, (D) = Vegetative (Knee Height), (E) = Early Reproductive (Earing), (F) = Reproductive Stage (Flowering), (G) = Grain Development, (H) = Maturity, (I) = Harvest												
(0) = Failure, (1) = Very Poor, (2) = Poor, (3) = Fair, (4) = Good, (5) = Very Good												

ZIMBABWE EARLY WARNING UNIT FOR FOOD SECURITY - AGROMETEOROLOGICAL CROP MONITORING & REPORT

Cropping Season: 19 95/96 Province: MATRUH District: BAHIG Report N.: 11 From: 4/3/96 To: 17/3/96

FORM N. 3	LIVESTOCK (Water Supplies, Grazing Availability, Livestock Change & Condition)
COMMERCIAL AREAS:	
COMMUNAL AREAS:	
<p>Enough water for both humans and livestock. Adequate grass in the wild. Livestock in good condition.</p>	
WATER SUPPLIES (Dams, Rivers, Springs, Boreholes & Wells)	
<p>Bore in flow. Water levels in boreholes and wells rising.</p>	
WEATHER (Rainfall, Dry & Wet Spell, Abnormal Temperature)	
<p>Hot days and cool nights. Rainfall for the period = 22mm (12/3/96 inclusive) Rainfall to date = 772 mm.</p>	

ZIMBABWE EARLY WARNING UNIT FOR FOOD SECURITY - AGROMETEOROLOGICAL CROP MONITORING AND REPORT

Cropping Season 19 96 / 97 Province MANICALAND District BUHERA Report No: 11 From: 9/3/97 To 22/3/97

FORM No. 1	PLANTED AREA (Ha)	PLANT. DEKAD	STAGE	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANT. DEKAD	STAGE	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANT. DEKAD	STAGE	COND.	EST. YIELD
Farming Sector															
MAIZE															
1 - L.S.O.A.															
2 - S.S.O.A.															
3 - O.A.	26500	3/11	H	-3	1	9500	3/11	H	4	0.7	21000	3/11	H	3	0.6
4 - R.A.															
COMMENTS:															
Early crop at hard dough stage						Early crop at hard dough stage						Crop at hard dough stage.			
GROUNDNUTS															
SOYABEANS															
RAPOKO															
1 - L.S.O.A.															
2 - S.S.O.A.															
3 - O.A.	7200	3/11	H	3	0.5	12800	3/11	H	4	0.6	NIL				
4 - R.A.															
COMMENTS:															
Crop at hard dough stage						Pulling up vines of early crop									
DEPARTMENT OF AGRICULTURE MANICALAND REGION															
19 MAR 1997															
P. O. BOX 143, MUTARE															
CROP STAGE															
CROP CONDITION															
(A) = Planting, (B) = Re-Planting (C) = Emergence, (D) = Vegetative (Knee Height), (E) = Early Reproductive (Earling), (F) = Reproductive Stage (Flowering), (G) = Grain Development, (H) = Maturity, (I) = Harvest															
(0) = Failure, (1) = Very Poor, (2) = Poor, (3) = Fair, (4) = Good (5) = Very Good															

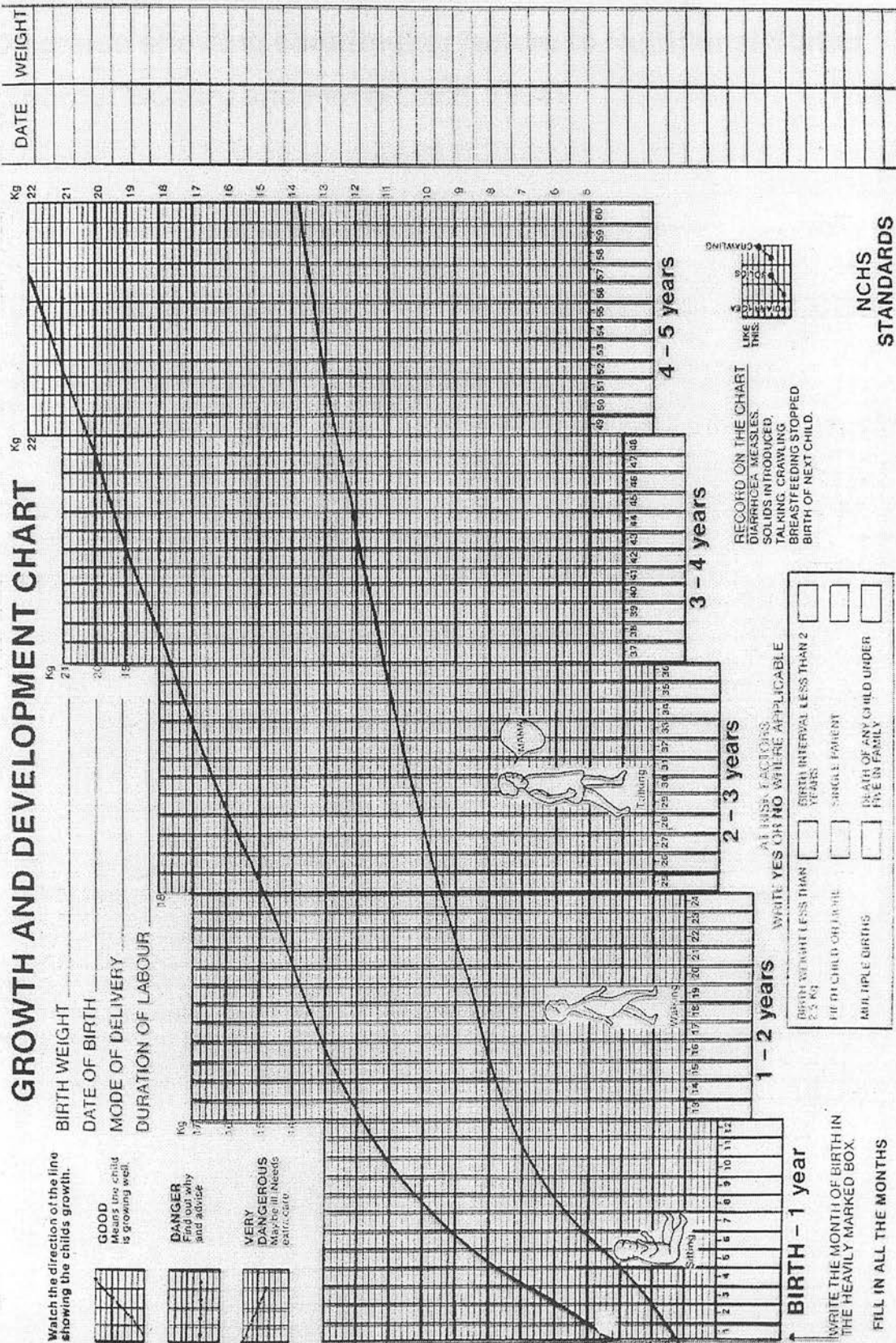
ZIMBABWE EARLY WARNING UNIT FOR FOOD SECURITY - AGROMETEOROLOGICAL CROP MONITORING AND REPORT

Cropping Season 19 96 / 97 Province MANICALAND District BUHERA Report No. 11 From 9/3/97 To 22/3/97

FORM No. 3	PLANTED AREA (Ha)	PLANTING STAGE	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANTING STAGE	COND.	EST. YIELD	PLANTED AREA (Ha)	PLANTING STAGE	COND.	EST. YIELD
SUNFLOWERS												
Farming Sector												
1 - L.S.O.A.												
2 - S.S.O.A.												
3 - C.A.	5000	1/12	G	3	0.6	300	3/11	G	3	NIL		
4 - R.A.												
COMMENTS:				Early crop maturing				COMMENTS:				
								Bolls about to mature				
EDIBLE BEANS												
Farming Sector												
1 - L.S.O.A.												
2 - S.S.O.A.												
3 - C.A.												
4 - R.A.												
COMMENTS:								COMMENTS:				
ORIENTAL TOBACCO												
Farming Sector												
1 - L.S.O.A.												
2 - S.S.O.A.												
3 - C.A.												
4 - R.A.												
COMMENTS:								COMMENTS:				
								Reaping and curing.				
BURLEY TOBACCO												
Farming Sector												
1 - L.S.O.A.												
2 - S.S.O.A.												
3 - C.A.												
4 - R.A.												
COMMENTS:								COMMENTS:				
CROP STAGE												
(A) = Planting, (B) = Re - Planting (C) = Emergence, (D) = Vegetative (Knee Height), (E) = Early Reproductive (Earling), (F) = Reproductive Stage (Flowering), (G) = Grain Development, (H) = Maturity, (I) = Harvest.												
(C) = Failure, (1) = Very Poor, (2) = Poor, (3) = Fair, (4) = Good (5) = Very Good												

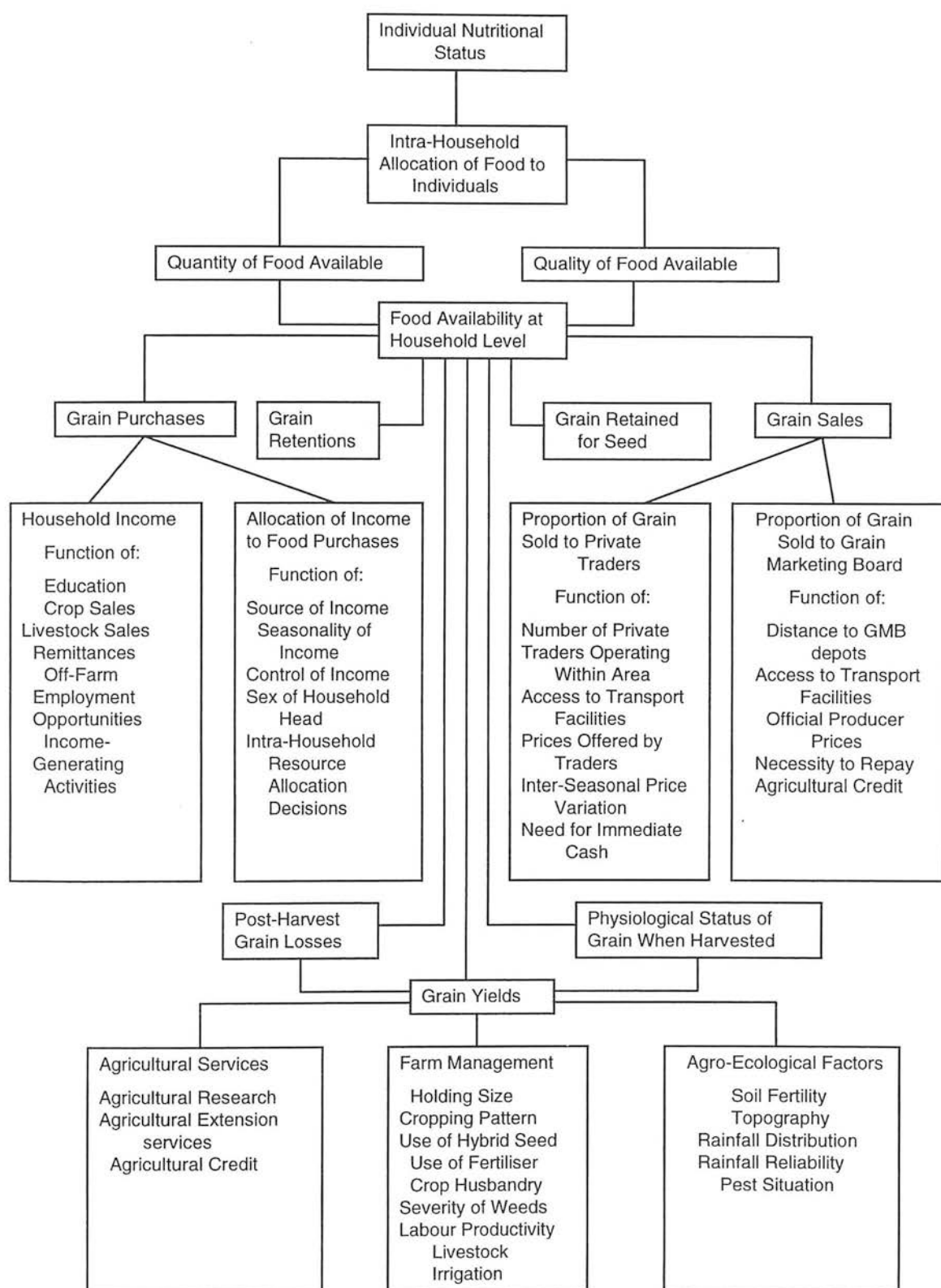
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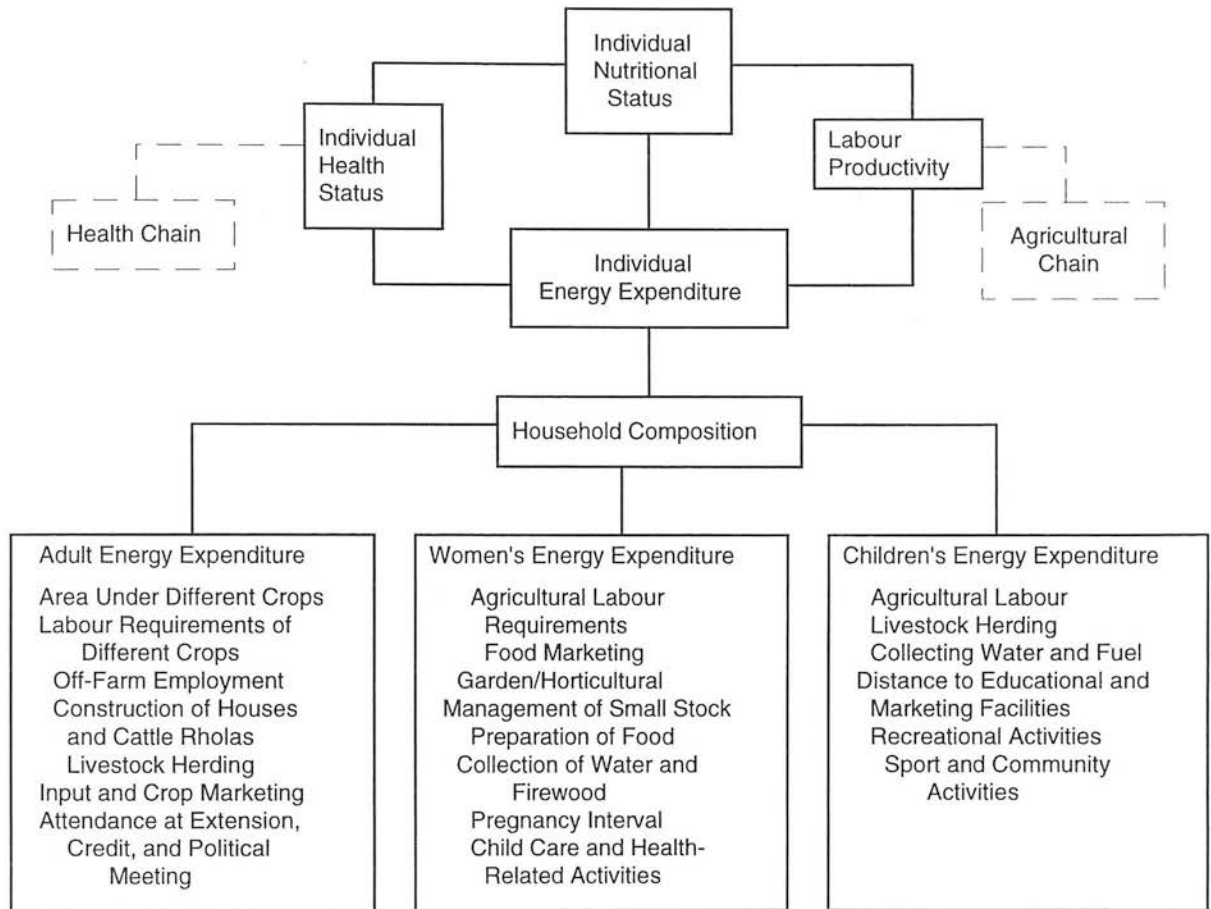
Growth monitoring chart

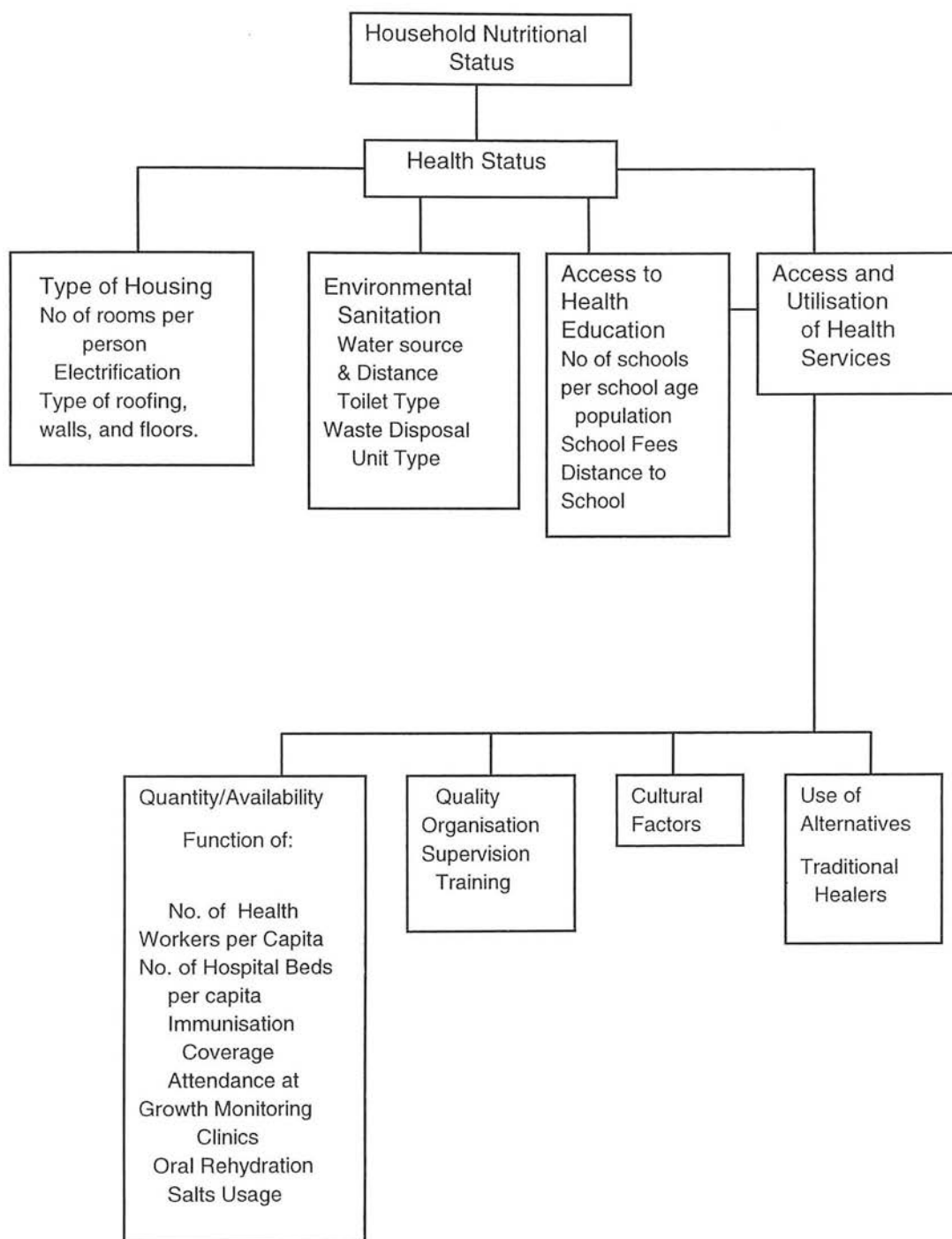


Appendix IV:

Diagrams showing contributing factors to Nutritional Status
(Source: Gundry and Ferro-Luzzi, 1994)







Appendix V:

Coding for Food Access component of Systems Dynamic Modelling Framework

```

ANIMAL_STOCKS_in_goat_equivs(t) =
ANIMAL_STOCKS_in_goat_equivs(t - dt) + (Animal_births +
Animal_purchases - Animal_deaths - Own_animals_for_consumption
- Animal_gifts - Animal_sales) * dt

INIT ANIMAL_STOCKS_in_goat_equivs = 10
Animal_births =
ANIMAL_STOCKS_in_goat_equivs*Animal_birth_fraction
Animal_purchases = Expenditure_animals/100
Animal_deaths =
ANIMAL_STOCKS_in_goat_equivs*Animal_death_fraction
Own_animals_for_consumption(o) =
ANIMAL_STOCKS_in_goat_equivs*0.01
Animal_gifts = No_of_men_away*0.1
Animal_sales = ANIMAL_STOCKS_in_goat_equivs*0.02-
Own_animals_for_consumption
CASH_in_Zim_dollars(t) = CASH_in_Zim_dollars(t - dt) +
(Income_animals + Income_crops + Casual_wages + Remittances -
Expenditure_animals - Expenditure_food -
Expenditure_agric_inputs - Expenditure_other) * dt

INIT CASH_in_Zim_dollars = 1200
Income_animals = Animal_sales/Price_of_goat
Income_crops = Crop_sales*Price_of_maize
Casual_wages =
IF(Local_job_mkt=1)THEN(Man_days_available*Rural_unskilled_dayr
ate)ELSE(0)
Remittances = No_of_men_away*(Urban_unskilled_salary-
Urban_living_costs)
Expenditure_animals =
IF(CASH_in_Zim_dollars>Price_of_goat*10)THEN(Price_of_goat)ELSE
(0)
Expenditure_food =
IF(CASH_in_Zim_dollars>100)THEN(Food_purchases/(kcal_per_kg_ma
ize*Price_of_maize))ELSE(0)
Expenditure_agric_inputs =
IF(Farmer_skill_level=1)THEN(CASH_in_Zim_dollars*.2)ELSE(0)
Expenditure_other =
IF(CASH_in_Zim_dollars>500)THEN(Consumer_durables+Health_fees+S
chool_fees)ELSE(0)
FOOD_FOR_PERIOD_in_kcals(t) = FOOD_FOR_PERIOD_in_kcals(t - dt)
+ (Own_grain_for_consumption + Wild_foods +
Own_animals_for_consumption + Food_purchases + Grain_rec'd +
Food_aid + Animals_rec'd - Consumed) * dt

INIT FOOD_FOR_PERIOD_in_kcals = 200000
Own_grain_for_consumption(o) =
IF(TIME=0)THEN(STOCKS_OWN_PROD'N_in_kgs_maize_equivs)ELSE(IF(Qu
ality_of_next_harvest=1)THEN(IF(STOCKS_OWN_PROD'N_in_kgs_maize_
equivs>((H'hold_kcals_per_mth*0.9)/kcal_per_kg_maize)*Months_
to_next_harvest))THEN((H'hold_kcals_per_mth*0.9)/kcal_per_kg_m
aize)ELSE(STOCKS_OWN_PROD'N_in_kgs_maize_equivs/Months_to_next_
harvest))ELSE(IF(STOCKS_OWN_PROD'N_in_kgs_maize_equivs>((H'hol
d_kcals_per_mth*0.9)/kcal_per_kg_maize)*(12+Months_to_next_har
vest)))THEN((H'hold_kcals_per_mth*0.9)/kcal_per_kg_maize)ELSE(
STOCKS_OWN_PROD'N_in_kgs_maize_equivs/(12+Months_to_next_harves
t))))

```



```

Wild_foods =
IF(Quality_of_local_ecosystem=1) THEN (FOOD_FOR_PERIOD_in_kcals*.
1) ELSE (0)
Own_animals_for_consumption(o) =
ANIMAL_STOCKS_in_goat_equivs*0.01
Food_purchases =
IF((H'hold_kcals_per_mth*0.9)/kcals_per_kg_maize>Own_grain_for_
consumption) THEN ((H'hold_kcals_per_mth*0.9)/kcals_per_kg_maize
-Own_grain_for_consumption)*kcals_per_kg_maize ELSE (0)
Grain_rec'd = No_of_men_away*5*kcals_per_kg_maize
Food_aid =
IF(FOOD_FOR_PERIOD_in_kcals>H'hold_kcals_per_mth) THEN (0) ELSE (IF
(Food_aid_op'ns?=1) THEN (50*kcals_per_kg_maize) ELSE (0))
Animals_rec'd = No_of_men_away*.01*kcals_per_goat
Consumed = FOOD_FOR_PERIOD_in_kcals
STOCKS_OWN_PROD'N_in_kgs_maize_equivs(t) =
STOCKS_OWN_PROD'N_in_kgs_maize_equivs(t - dt) + (Harvest -
Own_grain_for_consumption - Crop_losses_PH - Grain_gifts -
Crop_sales) * dt

INIT STOCKS_OWN_PROD'N_in_kgs_maize_equivs = 50
Harvest =
IF(TIME=0) THEN (Area_planted_ha*Yield_kgs_per_ha) ELSE (0)
Own_grain_for_consumption(o) =
IF(TIME=0) THEN (STOCKS_OWN_PROD'N_in_kgs_maize_equivs) ELSE (IF (Qu
ality_of_next_harvest=1) THEN (IF (STOCKS_OWN_PROD'N_in_kgs_maize_
equivs>((H'hold_kcals_per_mth*0.9)/kcals_per_kg_maize)*Months_
to_next_harvest)) THEN ((H'hold_kcals_per_mth*0.9)/kcals_per_kg_m
aize) ELSE (STOCKS_OWN_PROD'N_in_kgs_maize_equivs/Months_to_next_
harvest)) ELSE (IF (STOCKS_OWN_PROD'N_in_kgs_maize_equivs>((H'hol
d_kcals_per_mth*0.9)/kcals_per_kg_maize)*(12+Months_to_next_har
vest))) THEN ((H'hold_kcals_per_mth*0.9)/kcals_per_kg_maize) ELSE (
STOCKS_OWN_PROD'N_in_kgs_maize_equivs/(12+Months_to_next_harves
t))))
Crop_losses_PH =
IF(Farmer_skill_level=1) THEN (STOCKS_OWN_PROD'N_in_kgs_maize_equ
ivs*.01) ELSE (STOCKS_OWN_PROD'N_in_kgs_maize_equivs*.05)
Grain_gifts = No_of_men_away*10
Crop_sales = (STOCKS_OWN_PROD'N_in_kgs_maize_equivs-
(Own_grain_for_consumption*(12+Months_to_next_harvest)))
Animal_birth_fraction = 0
Animal_death_fraction = 0
Area_planted_ha = 1
Consumer_durables = 100
Farmer_skill_level = 1
Fee_per_child = 10
Food_aid_op'ns? = 0
H'hold_kcals_per_mth = 300000
Health_fees = 10
kcals_per_goat = 100000
kcals_per_kg_maize = 5000
Local_job_mkt = 1
Man_days_available = 10
Months_to_next_harvest = 13-TIME
No_children = 2
No_of_men_away = 1
Price_of_goat = 100
Price_of_maize =
If(Quality_of_next_harvest=1) THEN (10) ELSE (10+10/Months_to_next_
harvest)

```

```
Quality_of_local_ecosystem =  
IF(Months_to_next_harvest>6)THEN(0)ELSE(1)  
Quality_of_next_harvest = IF(TIME>6)THEN(0)ELSE(0)  
Rural_unskilled_dayrate = 10  
School_fees = Fee_per_child*No_children  
Urban_living_costs = 400  
Urban_unskilled_salary = 800  
Yield_kgs_per_ha =  
IF(Expenditure_agric_inputs>100)THEN(1500)ELSE(1000)
```

Appendix VI:

Coding for Health/Nutrition component of Systems Dynamic Modelling Framework

```

ADULTS_FOOD(t) = ADULTS_FOOD(t - dt) + (Food_to_A - A_consumption) *
dt
INIT ADULTS_FOOD = 1800000
Food_to_A =
FOOD_FOR_PERIOD*Adults_req'ts/(Adults_req'ts+Childrens_req'ts)
A_consumption = ADULTS_FOOD
ADULTS_HEALTHY(t) = ADULTS_HEALTHY(t - dt) + (A_recover - A_get_sick
- A_starve_or_feed) * dt

INIT ADULTS_HEALTHY = 200
A_recover = ADULTS_SICK*A_recovery_rate
A_get_sick = ADULTS_HEALTHY*A_infection_rate
A_starve_or_feed = IF(ADULTS_FOOD<Adults_req'ts) THEN
ADULTS_HEALTHY*0.1 ELSE-ADULTS_MALN*0.1
ADULTS_MALN(t) = ADULTS_MALN(t - dt) + (A_maln_recover +
A_starve_or_feed - A_maln_get_sick) * dt

INIT ADULTS_MALN = 100
A_maln_recover = ADULTS_S&M*A_maln_recovery_rate
A_starve_or_feed = IF(ADULTS_FOOD<Adults_req'ts) THEN
ADULTS_HEALTHY*0.1 ELSE-ADULTS_MALN*0.1
A_maln_get_sick = ADULTS_MALN*A_maln_infection_rate
ADULTS_S&M(t) = ADULTS_S&M(t - dt) + (A_maln_get_sick +
A_sick_starve_or_feed - A_maln_recover) * dt

INIT ADULTS_S&M = 100
A_maln_get_sick = ADULTS_MALN*A_maln_infection_rate
A_sick_starve_or_feed = IF(ADULTS_FOOD<Adults_req'ts) THEN
ADULTS_SICK*0.1 ELSE -ADULTS_S&M*0.1
A_maln_recover = ADULTS_S&M*A_maln_recovery_rate
ADULTS_SICK(t) = ADULTS_SICK(t - dt) + (A_get_sick - A_recover -
A_sick_starve_or_feed) * dt

INIT ADULTS_SICK = 100
A_get_sick = ADULTS_HEALTHY*A_infection_rate
A_recover = ADULTS_SICK*A_recovery_rate
A_sick_starve_or_feed = IF(ADULTS_FOOD<Adults_req'ts) THEN
ADULTS_SICK*0.1 ELSE -ADULTS_S&M*0.1
CHILDRENS_FOOD(t) = CHILDRENS_FOOD(t - dt) + (Food_to_C -
C_consumption) * dt

INIT CHILDRENS_FOOD = 3000000
Food_to_C =
FOOD_FOR_PERIOD*Childrens_req'ts/(Adults_req'ts+Childrens_req'ts)
C_consumption = CHILDRENS_FOOD
CHILDREN_HEALTHY(t) = CHILDREN_HEALTHY(t - dt) + (C_recover -
C_get_sick - C_starve_or_feed) * dt

INIT CHILDREN_HEALTHY = 1000
C_recover = CHILDREN_SICK*C_recovery_rate
C_get_sick = CHILDREN_HEALTHY*C_infection_rate
C_starve_or_feed = IF(CHILDRENS_FOOD<Childrens_req'ts) THEN
CHILDREN_HEALTHY*0.1 ELSE -CHILDREN_MALN*0.1
CHILDREN_MALN(t) = CHILDREN_MALN(t - dt) + (C_maln_recover +
C_starve_or_feed - C_maln_get_sick) * dt

INIT CHILDREN_MALN = 200
C_maln_recover = CHILDREN_S&M*C_maln_recovery_rate
C_starve_or_feed = IF(CHILDRENS_FOOD<Childrens_req'ts) THEN
CHILDREN_HEALTHY*0.1 ELSE -CHILDREN_MALN*0.1

```

```

C_maln_get_sick = CHILDREN_MALN*C_maln_infection_rate
CHILDREN_S&M(t) = CHILDREN_S&M(t - dt) + (C_maln_get_sick +
C_sick_starve_or_feed - C_maln_recover) * dt

INIT CHILDREN_S&M = 100
C_maln_get_sick = CHILDREN_MALN*C_maln_infection_rate
C_sick_starve_or_feed = IF(CHILDRENS_FOOD<Childrens_req'ts) THEN
CHILDREN_SICK*0.1 ELSE-CHILDREN_S&M*0.1
C_maln_recover = CHILDREN_S&M*C_maln_recovery_rate
CHILDREN_SICK(t) = CHILDREN_SICK(t - dt) + (C_get_sick - C_recover -
C_sick_starve_or_feed) * dt

INIT CHILDREN_SICK = 200
C_get_sick = CHILDREN_HEALTHY*C_infection_rate
C_recover = CHILDREN_SICK*C_recovery_rate
C_sick_starve_or_feed = IF(CHILDRENS_FOOD<Childrens_req'ts) THEN
CHILDREN_SICK*0.1 ELSE-CHILDREN_S&M*0.1
FOOD_FOR_PERIOD(t) = FOOD_FOR_PERIOD(t - dt) + (Food_access -
Food_to_C - Food_to_A) * dt

INIT FOOD_FOR_PERIOD = 4700000
Food_access = IF(TIME<3)OR(TIME>8)THEN(RANDOM(3800000,5000000))ELSE
(RANDOM(3000000,3800000))
Food_to_C =
FOOD_FOR_PERIOD*Childrens_req'ts/(Adults_req'ts+Childrens_req'ts)
Food_to_A =
FOOD_FOR_PERIOD*Adults_req'ts/(Adults_req'ts+Childrens_req'ts)
Adults_req'ts =
ADULTS_HEALTHY*2500+(ADULTS_MALN+ADULTS_S&M+ADULTS_SICK)*3000
A_infection_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.1,0.2))ELSE(RANDOM(0.2,0.3))
A_maln_infection_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.2,0.3))ELSE(RANDOM(0.3,0.4))
A_maln_recovery_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.15,0.25))ELSE(RANDOM(0.25,0.35))
A_recovery_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.05,0.15))ELSE(RANDOM(0.15,0.25))
Childrens_req'ts =
CHILDREN_HEALTHY*1500+(CHILDREN_MALN+CHILDREN_S&M+CHILDREN_SICK)*2000
C_infection_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.2,0.3))ELSE(RANDOM(0.3,0.4))
C_maln_infection_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.3,0.4))ELSE(RANDOM(0.4,0.5))
C_maln_recovery_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.25,0.35))ELSE(RANDOM(0.35,0.45))
C_recovery_rate =
IF(TIME<3)OR(TIME>8)THEN(RANDOM(0.15,0.25))ELSE(RANDOM(0.25,0.35))

```

Appendix VII:

Coding for revised Health/Nutrition component of Systems Dynamic Modelling Framework

```

Adult_deaths:_hunger(t) = Adult_deaths:_hunger(t - dt) +
(Malnourished_adults_starve + Sick_adults_starve) * dt

INIT Adult_deaths:_hunger = 0
Malnourished_adults_starve = IF Adults'_needs_satisfied_% < 80 THEN
0.03*Malnourished_adults ELSE 0.01
Sick_adults_starve = IF Adults'_needs_satisfied_% < 70 THEN
0.02*Sick_&_malnourished_adults ELSE IF Adults'_needs_satisfied_% <
80 THEN 0.01*Sick_&_malnourished_adults ELSE 0.005
Adult_deaths:_illness(t) = Adult_deaths:_illness(t - dt) +
(Sick_adults_die + Malnourished_adults_die) * dt

INIT Adult_deaths:_illness = 0
Sick_adults_die = Sick_adults*Sick_death_rate_A
Malnourished_adults_die =
Sick_&_malnourished_adults*Sick_&_maln_death_rate_A
Available_food_for_period(t) = Available_food_for_period(t - dt) +
(From_food_module - Consumed_by_children - Consumed_by_adults) * dt

INIT Available_food_for_period = 120000000
From_food_module = IF TIME < 10 THEN 5000*2400*10 ELSE IF TIME < 19
THEN 5000* 2200*10 ELSE IF TIME< 28 THEN 5000*2000*10 ELSE
5000*2200*10
Consumed_by_children = IF Available_food_for_period <
Total_requirements_for_period THEN
1.05*(Available_food_for_period*(Childrens'_period_requirements/Total
_requirements_for_period)) ELSE
Available_food_for_period*(Childrens'_period_requirements/Total_requi
rements_for_period)
Consumed_by_adults = IF Available_food_for_period <
Total_requirements_for_period THEN Available_food_for_period-
1.05*(Available_food_for_period*(Childrens'_period_requirements/Total
_requirements_for_period)) ELSE
Available_food_for_period*(Adults'_period_requirements/Total_requirem
ents_for_period)
Child_deaths:_hunger(t) = Child_deaths:_hunger(t - dt) +
(Malnourished_children_starve + Sick_children_starve) * dt

INIT Child_deaths:_hunger = 0
Malnourished_children_starve = IF Childrens'_needs_satisfied_% <80
THEN 0.04*Malnourished_children ELSE 0.01
Sick_children_starve = IF Childrens'_needs_satisfied_% < 70 THEN
0.03*Sick_&_malnourished_children ELSE IF
Childrens'_needs_satisfied_% < 80 THEN
0.02*Sick_&_malnourished_children ELSE
0.01*Sick_&_malnourished_children
Child_deaths:_illness(t) = Child_deaths:_illness(t - dt) +
(Sick_children_die + Malnourished_children_die) * dt

INIT Child_deaths:_illness = 0
Sick_children_die = Sick_children*Sick_death_rate_C
Malnourished_children_die =
Sick_&_malnourished_children*Sick_&_maln_death_rate_C
Healthy_adults(t) = Healthy_adults(t - dt) + (Migrants_or_emigrants -
Adults_get_malnourished_or_fed - Adults_get_sick_or_recover) * dt

INIT Healthy_adults = 1500
Migrants_or_emigrants = 0*No__of_men_away*Healthy_adults

```



```

Adults_get_malnourished_or_fed = IF Adults'_needs_satisfied_% > 110
THEN -0.1*Malnourished_adults ELSE IF Adults'_needs_satisfied_% > 100
THEN -0.05*Malnourished_adults ELSE IF Adults'_needs_satisfied_% > 90
THEN 0.05*Healthy_adults ELSE IF Adults'_needs_satisfied_% >80 THEN
0.1*Healthy_adults ELSE IF Adults'_needs_satisfied_% > 70 THEN
0.2*Healthy_adults ELSE 0.3*Healthy_adults
Adults_get_sick_or_recover =
(Healthy_adults*Healthy_infection_rate_A)-
(Sick_adults*Sick_recovery_rate_A)
Healthy_children(t) = Healthy_children(t - dt) + (Healthy_births -
Children_get_malnourished_or_fed - Children_get_sick_or_recover) * dt

```

```

INIT Healthy_children = 2000
Healthy_births = Healthy_adults*Birth_rate
Children_get_malnourished_or_fed = IF Childrens'_needs_satisfied_% >
110 THEN -0.1*Malnourished_children ELSE IF
Childrens'_needs_satisfied_% > 100 THEN -0.05*Malnourished_children
ELSE IF Childrens'_needs_satisfied_% > 90 THEN 0.05*Healthy_children
ELSE IF Childrens'_needs_satisfied_% > 80 THEN 0.1*Healthy_children
ELSE IF Childrens'_needs_satisfied_% > 70 THEN 0.2*Healthy_children
ELSE 0.3*Healthy_children
Children_get_sick_or_recover =
(Healthy_children*Healthy_infection_rate_C)-
(Sick_children*Sick_recovery_rate_C)
Malnourished_adults(t) = Malnourished_adults(t - dt) +
(Adults_get_malnourished_or_fed - Adults_get_S&M_or_just_malnourished
- Malnourished_adults_starve) * dt

```

```

INIT Malnourished_adults = 200
Adults_get_malnourished_or_fed = IF Adults'_needs_satisfied_% > 110
THEN -0.1*Malnourished_adults ELSE IF Adults'_needs_satisfied_% > 100
THEN -0.05*Malnourished_adults ELSE IF Adults'_needs_satisfied_% > 90
THEN 0.05*Healthy_adults ELSE IF Adults'_needs_satisfied_% >80 THEN
0.1*Healthy_adults ELSE IF Adults'_needs_satisfied_% > 70 THEN
0.2*Healthy_adults ELSE 0.3*Healthy_adults
Adults_get_S&M_or_just_malnourished =
(Malnourished_adults*Malnourished_infection_rate_A)-
(Sick_&_malnourished_adults*Sick_&_maln_recovery_rate_A)
Malnourished_adults_starve = IF Adults'_needs_satisfied_% < 80 THEN
0.03*Malnourished_adults ELSE 0.01
Malnourished_children(t) = Malnourished_children(t - dt) +
(Children_get_malnourished_or_fed + Malnourished_births -
Children_get_S&M_or_just_malnourished - Malnourished_children_starve)
* dt

```

```

INIT Malnourished_children = 600
Children_get_malnourished_or_fed = IF Childrens'_needs_satisfied_% >
110 THEN -0.1*Malnourished_children ELSE IF
Childrens'_needs_satisfied_% > 100 THEN -0.05*Malnourished_children
ELSE IF Childrens'_needs_satisfied_% > 90 THEN 0.05*Healthy_children
ELSE IF Childrens'_needs_satisfied_% > 80 THEN 0.1*Healthy_children
ELSE IF Childrens'_needs_satisfied_% > 70 THEN 0.2*Healthy_children
ELSE 0.3*Healthy_children
Malnourished_births = Malnourished_adults*Birth_rate
Children_get_S&M_or_just_malnourished =
(Malnourished_children*Malnourished_infection_rate_C)-
(Sick_&_malnourished_children*Sick_&_maln_recovery_rate_C)
Malnourished_children_starve = IF Childrens'_needs_satisfied_% <80
THEN 0.04*Malnourished_children ELSE 0.01

```

```

Sick_&_malnourished_adults(t) = Sick_&_malnourished_adults(t - dt) +
(Adults_get_S&M_or_just_malnourished + Adults_get_S&M_or_just_sick -
Sick_adults_starve - Malnourished_adults_die) * dt

INIT Sick_&_malnourished_adults = 100
Adults_get_S&M_or_just_malnourished =
(Malnourished_adults*Malnourished_infection_rate_A)-
(Sick_&_malnourished_adults*Sick_&_maln_recovery_rate_A)
Adults_get_S&M_or_just_sick = IF Adults'_needs_satisfied_% > 110 THEN
-0.1*Sick_&_malnourished_adults ELSE IF Adults'_needs_satisfied_% >
100 THEN -0.05*Sick_&_malnourished_adults ELSE IF
Adults'_needs_satisfied_% > 90 THEN 0.05*Sick_adults ELSE IF
Adults'_needs_satisfied_% > 80 THEN 0.1*Sick_adults ELSE IF
Adults'_needs_satisfied_% > 70 THEN 0.2*Sick_adults ELSE
0.3*Sick_adults
Sick_adults_starve = IF Adults'_needs_satisfied_% < 70 THEN
0.02*Sick_&_malnourished_adults ELSE IF Adults'_needs_satisfied_% <
80 THEN 0.01*Sick_&_malnourished_adults ELSE 0.005
Malnourished_adults_die =
Sick_&_malnourished_adults*Sick_&_maln_death_rate_A
Sick_&_malnourished_children(t) = Sick_&_malnourished_children(t -
dt) + (Children_get_S&M_or_just_malnourished +
Children_get_S&M_or_just_sick - Sick_children_starve -
Malnourished_children_die) * dt

INIT Sick_&_malnourished_children = 100
Children_get_S&M_or_just_malnourished =
(Malnourished_children*Malnourished_infection_rate_C)-
(Sick_&_malnourished_children*Sick_&_maln_recovery_rate_C)
Children_get_S&M_or_just_sick = IF Childrens'_needs_satisfied_% > 110
THEN -0.1*Sick_&_malnourished_children ELSE IF
Childrens'_needs_satisfied_% > 100 THEN -
0.05*Sick_&_malnourished_children ELSE IF
Childrens'_needs_satisfied_% > 90 THEN 0.05*Sick_children ELSE IF
Childrens'_needs_satisfied_% > 80 THEN 0.1*Sick_children ELSE IF
Childrens'_needs_satisfied_% > 70 THEN 0.2*Sick_children ELSE
0.3*Sick_children
Sick_children_starve = IF Childrens'_needs_satisfied_% < 70 THEN
0.03*Sick_&_malnourished_children ELSE IF
Childrens'_needs_satisfied_% < 80 THEN
0.02*Sick_&_malnourished_children ELSE
0.01*Sick_&_malnourished_children
Malnourished_children_die =
Sick_&_malnourished_children*Sick_&_maln_death_rate_C
Sick_adults(t) = Sick_adults(t - dt) + (Adults_get_sick_or_recover -
Sick_adults_die - Adults_get_S&M_or_just_sick) * dt

INIT Sick_adults = 200
Adults_get_sick_or_recover =
(Healthy_adults*Healthy_infection_rate_A)-
(Sick_adults*Sick_recovery_rate_A)
Sick_adults_die = Sick_adults*Sick_death_rate_A
Adults_get_S&M_or_just_sick = IF Adults'_needs_satisfied_% > 110 THEN
-0.1*Sick_&_malnourished_adults ELSE IF Adults'_needs_satisfied_% >
100 THEN -0.05*Sick_&_malnourished_adults ELSE IF
Adults'_needs_satisfied_% > 90 THEN 0.05*Sick_adults ELSE IF
Adults'_needs_satisfied_% > 80 THEN 0.1*Sick_adults ELSE IF
Adults'_needs_satisfied_% > 70 THEN 0.2*Sick_adults ELSE
0.3*Sick_adults

```

```

Sick_children(t) = Sick_children(t - dt) +
(Children_get_sick_or_recover + Sick_births - Sick_children_die -
Children_get_S&M_or_just_sick) * dt

INIT Sick_children = 300
Children_get_sick_or_recover =
(Healthy_children*Healthy_infection_rate_C)-
(Sick_children*Sick_recovery_rate_C)
Sick_births = (Sick_&_malnourished_adults+Sick_adults)*Birth_rate
Sick_children_die = Sick_children*Sick_death_rate_C
Children_get_S&M_or_just_sick = IF Childrens'_needs_satisfied_% > 110
THEN -0.1*Sick_&_malnourished_children ELSE IF
Childrens'_needs_satisfied_% > 100 THEN -
0.05*Sick_&_malnourished_children ELSE IF
Childrens'_needs_satisfied_% > 90 THEN 0.05*Sick_children ELSE IF
Childrens'_needs_satisfied_% > 80 THEN 0.1*Sick_children ELSE IF
Childrens'_needs_satisfied_% > 70 THEN 0.2*Sick_children ELSE
0.3*Sick_children
Access_to_clinics = 1
Access_to_water = 1
Adults'_daily_requirements =
Healthy_adults*Healthy_daily_calories_A+Malnourished_adults*Malnouris
hed_daily_calories_A+Sick_adults*Sick_daily_calories_A+Sick_&_malnour
ished_adults*Sick_&_maln_daily_calories_A
Adults'_needs_satisfied_% =
(Consumed_by_adults/Adults'_period_requirements)*100
Adults'_period_requirements =
Days_per_period*Adults'_daily_requirements
Birth_rate = 0.6*0.75*(1/60)
Childrens'_daily_requirements =
Healthy_children*Healthy_daily_calories_C+Malnourished_children*Malno
urished_daily_calories_C+Sick_children*Sick_daily_calories_C+Sick_&_m
alnourished_children*Sick_&_maln_daily_calories_C
Childrens'_needs_satisfied_% =
(Consumed_by_children/Childrens'_period_requirements)*100
Childrens'_period_requirements =
Days_per_period*Childrens'_daily_requirements
Days_per_period = 10
Diarrhoea_local_rate_A =
Diarrhoea_locational*Diarrhoea_T5_mean_A*Di_UR_bias_A
Diarrhoea_local_rate_C =
Diarrhoea_locational*Diarrhoea_T5_mean_C*Di_UR_bias_C
Diarrhoea_locational = MEAN (Access_to_water, Sanitation)
Diarrhoea_T5_mean_A = IF TIME < 27 THEN 0.01 ELSE 0.02
Diarrhoea_T5_mean_C = IF TIME < 27 THEN 0.02 ELSE 0.04
Di_UR_bias_A = 1.2
Di_UR_bias_C = 1.5
Healthy_daily_calories_A = 2500
Healthy_daily_calories_C = 2000
Healthy_infection_rate_A =
0.5*(Diarrhoea_local_rate_A+HIV_AIDS_local_rate_A+Malaria_local_rate_
A+Measles_local_rate_A+Respiratory_local_rate_A)
Healthy_infection_rate_C =
0.5*(Diarrhoea_local_rate_C+HIV_AIDS_local_rate_C+Malaria_local_rate_
C+Measles_local_rate_C+Respiratory_local_rate_C)
HIV_AIDS_local_rate_A =
HIV_AIDS_locational*HIV_AIDS_T5_mean_A*Hi_UR_bias_A
HIV_AIDS_local_rate_C =
HIV_AIDS_locational*HIV_AIDS_T5_mean_C*Hi_UR_bias_C
HIV_AIDS_locational = No_of_men_away
HIV_AIDS_T5_mean_A = 0.05

```

```

HIV_AIDS_T5_mean_C = 0.01
Hi_UR_bias_A = 1.2
Hi_UR_bias_C = 1.5
Housing = 1.5
Immunisation_rate = 0.5
Malaria_local_rate_A =
Malaria_locational*Malaria_T5_mean_A*Ma_UR_bias_A
Malaria_local_rate_C =
Malaria_locational*Malaria_T5_mean_C*Ma_UR_bias_C
Malaria_locational = No__of_men_away
Malaria_T5_mean_A = 0.02
Malaria_T5_mean_C = 0.02
Malnourished_daily_calories_A = 3000
Malnourished_daily_calories_C = 2400
Malnourished_infection_rate_A =
1.5*(Diarrhoea_local_rate_A+HIV_AIDS_local_rate_A+Malaria_local_rate_
A+Measles_local_rate_A+Respiratory_local_rate_A)
Malnourished_infection_rate_C =
1.5*(Diarrhoea_local_rate_C+HIV_AIDS_local_rate_C+Malaria_local_rate_
C+Measles_local_rate_C+Respiratory_local_rate_C)
Ma_UR_bias_A = 1.2
Ma_UR_bias_C = 1.5
Measles_local_rate_A =
Measles_locational*Measles_T5_mean_A*Me_UR_bias_A
Measles_local_rate_C =
Measles_locational*Measles_T5_mean_C*Me_UR_bias_C
Measles_locational = MEAN
(Immunisation_rate,Religion_&_customs, Sanitation)
Measles_T5_mean_A = .005
Measles_T5_mean_C = IF TIME < 15 OR TIME > 30 THEN 0.01 ELSE 0.02
Me_UR_bias_A = 1.2
Me_UR_bias_C = 1.5
No__of_men_away = 1
Recovery_locational = MEAN (Access_to_clinics,Religion_&_customs)
Religion_&_customs = 1
Respiratory_local_rate_A =
Respiratory_locational*Respiratory_T5_mean_A*Re_UR_bias_A
Respiratory_local_rate_C =
Respiratory_locational*Respiratory_T5_mean_C*Re_UR_bias_C
Respiratory_locational = MEAN
(Housing,Immunisation_rate,Religion_&_customs)
Respiratory_T5_mean_A = 0.05
Respiratory_T5_mean_C = 0.05
Re_UR_bias_A = 1.2
Re_UR_bias_C = 1.5
Sanitation = 0.5
Sick_&_maln_daily_calories_A = 3200
Sick_&_maln_daily_calories_C = 2600
Sick_&_maln_death_rate_A = 1-Sick_&_maln_recovery_rate_A
Sick_&_maln_death_rate_C = 1-Sick_&_maln_recovery_rate_C
Sick_&_maln_recovery_rate_A = (IF Malnourished_infection_rate_A > 0.5
THEN 0.95 ELSE 0.97)*Recovery_locational
Sick_&_maln_recovery_rate_C = (IF Malnourished_infection_rate_C > 0.4
THEN 0.95 ELSE 0.97)*Recovery_locational
Sick_daily_calories_A = 2800
Sick_daily_calories_C = 2200
Sick_death_rate_A = 1-Sick_recovery_rate_A
Sick_death_rate_C = 1-Sick_recovery_rate_C
Sick_recovery_rate_A = (IF Healthy_infection_rate_A >0.5 THEN 0.97
ELSE 0.99)*Recovery_locational

```

```
Sick_recovery_rate_C = (IF Healthy_infection_rate_C >0.4 THEN 0.97  
ELSE 0.99)*Recovery_locational  
Total_requirements_for_period =  
Adults'_period_requirements+Childrens'_period_requirements
```

Appendix VIII:

Copy of paper ‘Spatial simulation of rainfall data for crop production modelling in southern Africa’ by Wright et al. (1999)

Spatial Simulation of Rainfall Data for Crop Production Modeling in Southern Africa

JA Wright, Institute of Ecology & Resource Management, University of Edinburgh,
J Smith, Scottish Agricultural College, Edinburgh,
SW Gundry, Institute of Ecology & Resource Management, University of Edinburgh,
C Glasbey, Biomathematics and Statistics Scotland.

Abstract: This paper describes a methodology for simulating rainfall across a set of spatial units in areas where long-term meteorological records are available for a small number of sites only. The work forms part of a larger simulation model of the food system in a district of Zimbabwe. The simulation includes a crop production component, which models yields of maize, small grains and groundnuts on the basis of rainfall for 10-day periods or *dekads*. The model simulates production across 30 different spatial units (wards), thereby capturing environmental variability and facilitating modeling of trade in crops between wards. The network of meteorological stations around the district is sparse and few of these have long time series of rainfall records in Zimbabwe. Preliminary analysis of rainfall data for these stations suggested that intra-seasonal temporal correlation was negligible, but that rainfall at any given station was correlated with rainfall at neighbouring stations. This spatial correlation structure can be modeled using a multivariate normal distribution consisting of 30 related variables, representing dekadal rainfall in each of the 30 wards. For each ward, rainfall for each of the 36 dekads in the year was characterised by a mean and standard deviation, which were interpolated from surrounding meteorological stations. A covariance matrix derived from a distance measure was then be used to represent the spatial correlation between wards. Sets of random numbers were then drawn from this distribution to simulate rainfall across the wards in any given *dekad*. Cross-validation of estimated rainfall parameters against observed parameters for the one meteorological station within the district suggests that the interpolation process works well. The methodology developed is useful in situations where long-term climatic records are scarce and where rainfall shows pronounced spatial correlation, but negligible temporal correlation.

1 INTRODUCTION

This paper develops a methodology for spatial simulation of rainfall for areas where directly measured meteorological data are sparse, by interpolating measurements from surrounding rainfall stations. The methodology characterises the dekadal rainfall distribution across the wards through a multivariate normal distribution. It forms part of a simulation model of the food system in a region of Zimbabwe, which has been developed by an inter-disciplinary research group for use in food aid targeting [Gundry *et al.*, 1998]. This model includes components examining crop production, grain marketing [Vaze *et al.*, 1996], food consumption and onward linkages to human health and nutrition. The study is based in Buhara district, a semi-arid area where dryland production of maize, millet, sorghum, and groundnuts by smallholder farmers predominates. As substantial differences in climate exist within this district, crop production is modelled separately for the 30 different wards that make up the district. In common with several other maize models [e.g.

Brisson *et al.*, 1992], the effect of rainfall variability on yields is simulated using a 10-daily time-step or *dekad*. Climate assessment in such areas is problematic, since the network of meteorological stations in Zimbabwe is concentrated in the more productive land further north.

One solution is to use sophisticated interpolation techniques that make use of Cold Cloud Duration data from the NOAA-AVHRR satellite [Herman *et al.*, 1997]. The United States Geological Survey Africa Data Dissemination Service (USGS ADDS) has used this process to provide dekadal rainfall data interpolated to a raster grid since 1995. However, although these data have sufficient spatial resolution for the purposes of the current model, the length of time series available (three years) is too short for use in multiple simulations requiring climatic variability. In addition, the interpolation method used gives rainfall patterns inconsistent with variation in crop production and vegetation within the district. The USGS rainfall data suggest that average rainfall over this period is broadly similar across the district, yet household survey data suggest the widespread cultivation of

drought-resistant crops in the south of the district. As the USGS data appear to be inadequate for the wider model, a weather generator was developed to provide input to the crop models. The approach taken here differs from many other published weather generators [e.g. Leenhardt, 1999], in that spatial correlation in rainfall is explicitly modelled.

the values. The data were then standardised by computing means and standard deviations for each dekade at every station. The mean for each dekade was then subtracted from each value and the result was divided by the standard deviation.

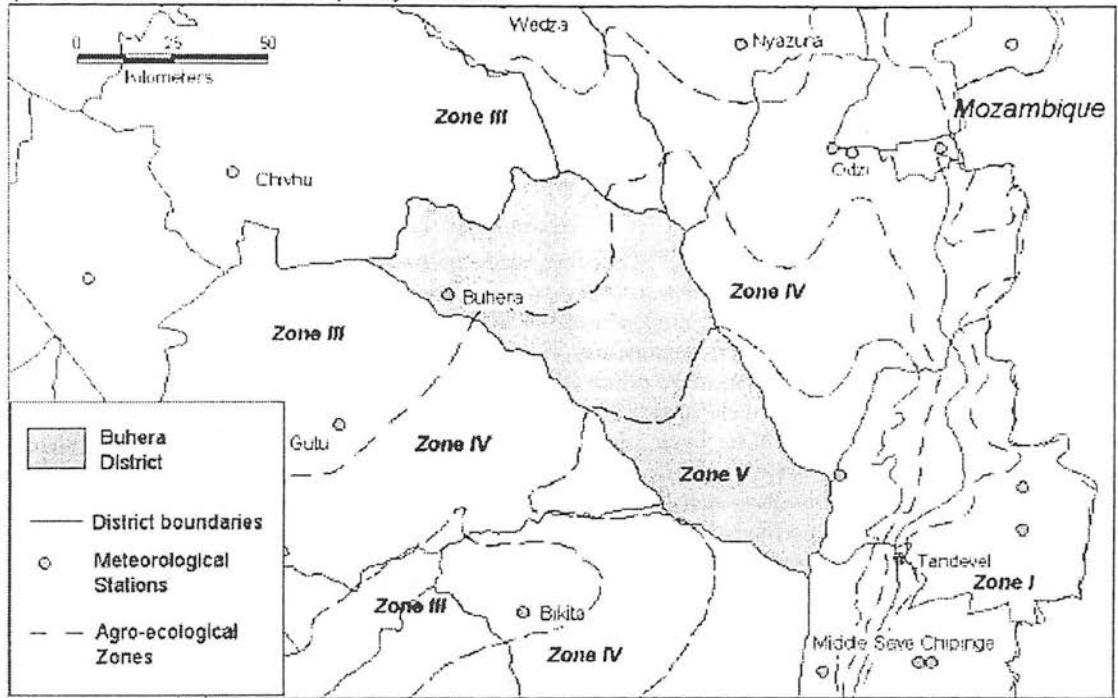


Figure 1: Map of Buhera district agro-ecological zones and meteorological stations used in interpolation.

2 METHODS

2.1 Data preparation

Dekadly rainfall data for 64 Zimbabwean meteorological stations were obtained from the USGS ADDS, covering the period 1952-1992. Since rainfall is known to contain a greater orographic component in the Eastern Highlands area to the east of Buhera, the analysis was restricted to 8 stations immediately surrounding Buhera but outside this upland region. This included one rainfall station lying in the northern part of the district itself. The location of the meteorological stations used is shown in Figure 1, together with agro-ecological zone boundaries for the area. The agro-ecological zones vary from Zone I (the wettest, with typical annual rainfall over 1,000 mm) to Zone V (the driest, with typical annual rainfall less than 600 mm). Buhera district straddles three of these zones: Zone III in the north through to Zone V in the south.

As the rainfall data had a skewed distribution, a logarithmic transformation was used to normalise

2.2 Assessment of temporal correlation

The transformed, standardised data were examined for evidence of spatial and temporal correlation. Correlation co-efficients were calculated using lags of up to 8 dekads for these stations, both including and excluding dry season dekads. Dekadly rainfall data were also aggregated by month and the same procedure was repeated using lags of up to 8 months. This analysis suggested little evidence of temporal correlation: for example, the correlation coefficient between rainfall in the current month and rainfall in the previous month was only 0.2. However, a preliminary exploration of the change in rainfall covariance with distance suggested that spatial correlation did exist (see later analysis). Consequently, the simulation made use of this spatial correlation structure, but not temporal correlation.

2.3 Assessment of spatial correlation

To examine spatial correlation, correlation coefficients were also calculated for each pair of rainfall stations using transformed, standardised data from all dekads.

This spatial correlation structure was simulated in two stages. Firstly, dekadal means and standard deviations for each ward were estimated from the station observations using a distance decay function. The reciprocal of distance squared was used to derive the weight for each station:

$$P_w = (\sum_{i=1..8} p_i D_{iw}^{-2}) / (\sum_{i=1..8} D_{iw}^{-2}) \quad [1]$$

{where P_w = dekadal mean or standard deviation of precipitation for ward w ; p_i = dekadal mean or standard deviation for each station; and D_{iw} = 3-dimensional distance between station i and ward w }

The 3-dimensional distance term in this equation (D_{iw}) was derived as follows:

$$D = \sqrt{(d^2 + ke^2)} \quad [2]$$

{where D = 3-dimensional distance, d = horizontal distance between two locations, k = a weighting factor for elevation, and e = difference in elevation between two points}

turn and estimating dekadal means and standard deviations for this omitted station from the other stations' data. The value of the weight was chosen so as to minimise the difference between estimated and observed dekadal rainfall parameters across all stations through an optimisation process.

Once a weight had been derived for elevation, this was used to compute three-dimensional distances between all pairs of stations. The rainfall covariance for each pair of stations was then plotted against distance. A function was fitted through simple regression that described the effect of distance on the rainfall covariance between points.

2.4 Generation of rainfall scenarios

Distances based on equation [2] above were then calculated between each of the wards in the district using a Geographical Information System. For each pair of wards, the covariance for rainfall was estimated based on the relationship derived with distance. A FORTRAN program was then used to sample random numbers from a truncated multivariate normal distribution for the 30 wards. The same covariance matrix was used to generate the values for each dekad, but means and standard

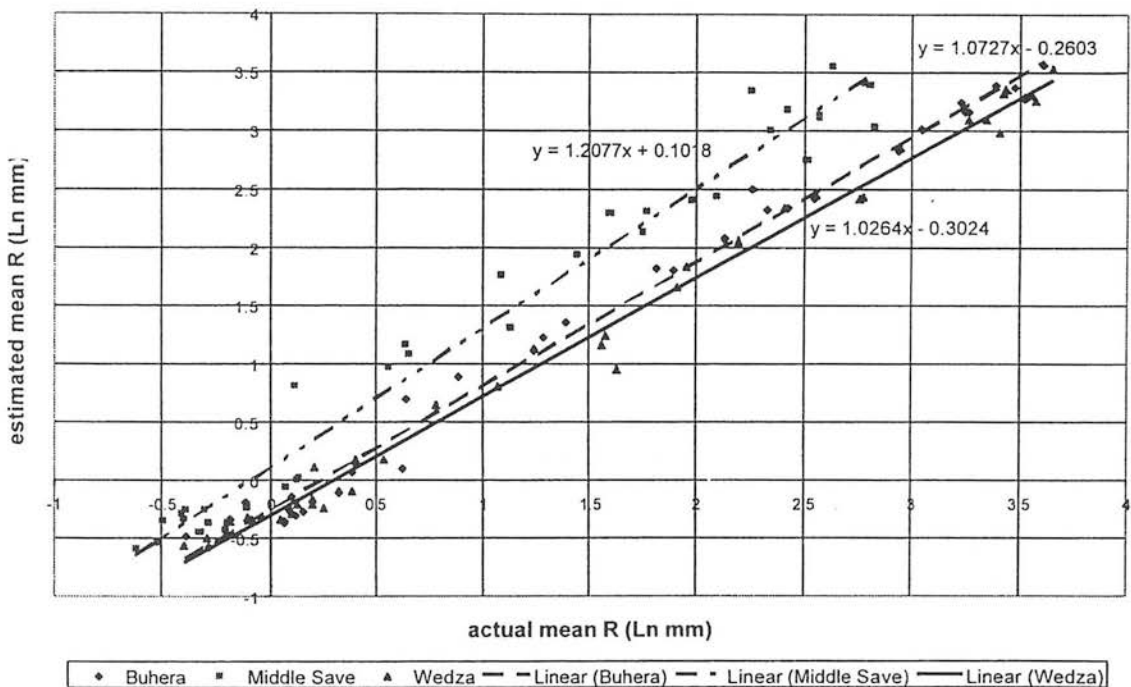


Figure 2: Results of cross-validation - estimated versus actual mean transformed rainfall by dekad for 3 sample meteorological stations

The weight factor for elevation (k) in this equation was estimated using a cross-validation process. This involved omitting the data for each station in

deviations varied from one dekad to the next.

3 RESULTS

The cross-validation exercise suggested a weight for difference in elevation of 140,000. Actual versus estimated mean rainfall for each dekad is shown in Figure 2. Cross-validation results for three of the eight original rainfall stations used are shown. When the Buhera station (which lies within the district as shown in Figure 1) was omitted and the remaining data points were used to estimate the mean and standard deviation of transformed rainfall by dekad, the model 'goodness of fit' remained high. When estimates of the mean and standard deviation were compared with observed data for this station, these gave a Root Mean Square Error of 0.30, suggesting that the method of estimating dekady rainfall parameters worked well at least in part of the district. Similarly, the omission of the data point at Wedza to the north of the district did not adversely affect the model 'goodness of fit'. However, the omission of the Middle Save meteorological station led to an over-estimation of mean rainfall by dekad. This is because Middle Save is the only data point lying in the drier agro-ecological zone (Zone V in Figure 1) to the south of Buhera and the other data points inadequately represent this zone. This data point is therefore one of the most critical to overall model performance.

A linear regression model was used to relate the rainfall covariance between two points to 3-dimensional distance, which had an R^2 of 0.41. This relationship with distance is illustrated for the correlation co-efficient for rainfall at any two points in Figure 3. Despite the relatively high 'goodness of fit' of this model, the rainfall stations are generally further apart than the wards and so the correlation between wards that are close together is somewhat difficult to gauge. In the absence of more detailed information, the linear relationship between covariance and distance was extrapolated to represent such shorter distances.

Figure 4 shows sample rainfall scenario for one year. In this illustration, total annual rainfall derived from the dekady model output has been linked to ward boundaries and the lower rainfall to the south of the district is clearly shown.

4 DISCUSSION & CONCLUSIONS

This paper illustrates a method of simulating rainfall across an arbitrary number of sites in situations where long-term meteorological records are scarce. The methodology is based on the assumption that the distribution of rainfall has remained largely unchanged since the 1950s. Although it has been suggested that rainfall patterns have changed since this date, in terms of national rainfall patterns, Gommers and Petrassi [1994: p. 16] note that there is 'no marked negative

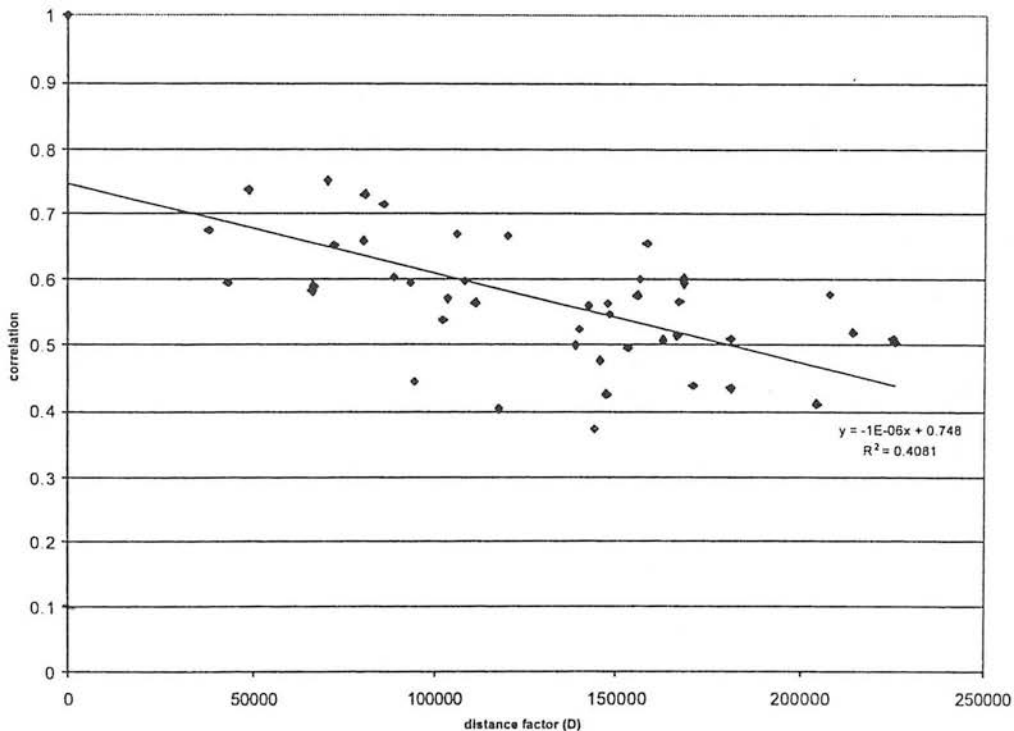


Figure 3: Relationship between 3-dimensional distance and rainfall correlation between pairs of meteorological stations

trend in rainfall' for a group of African countries including Zimbabwe. The Zimbabwean rainfall time series shows a slight increase up to 1979 and a slight decline thereafter [*ibid.*, p. 13], suggesting that nationally at least this assumption is justified. The method adopted here is useful where significant spatial correlation exists, but negligible short-term temporal correlation. However, the

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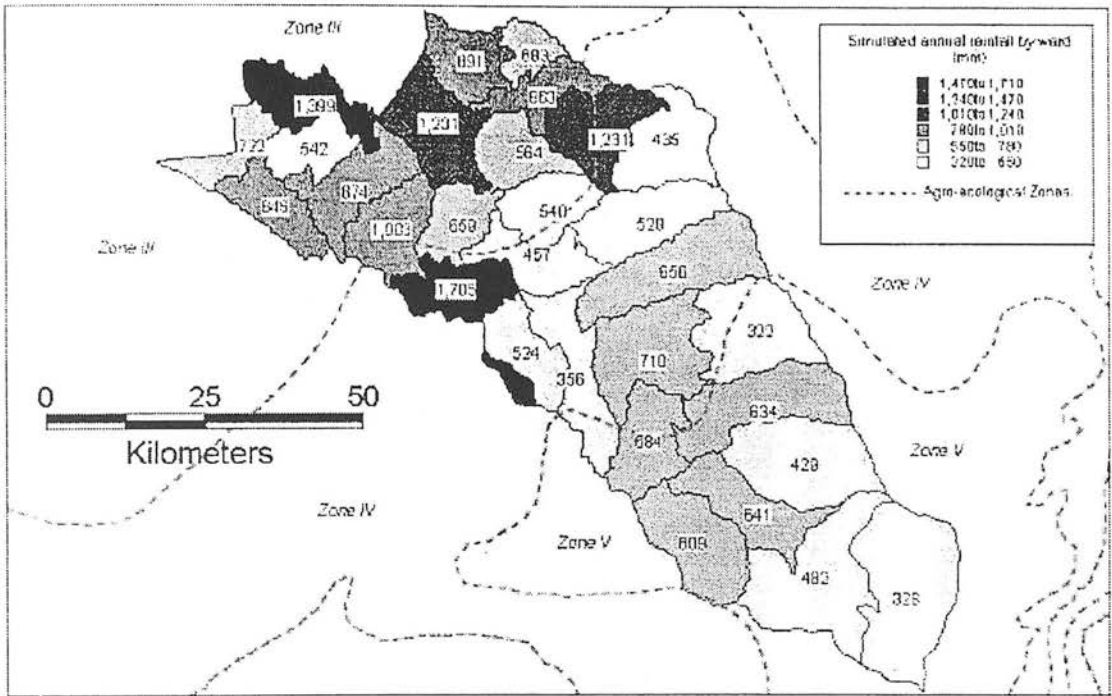


Figure 4: Sample model output, showing total annual rainfall scenarios by ward

methodology could be generalised to include temporal correlation. The absence of temporal correlation in this data set is surprising, as drought years in southern Africa are known to be related to El Nino-Southern Oscillation (ENSO) events. For example, earlier work [Cane *et al.*, 1994] identified a close relationship between sea surface temperatures measured using remote sensing and maize yields in Zimbabwe, whilst the Southern Oscillation Index has been used for crop production forecasting in South Africa [de Jager *et al.*, 1998]. On this basis, below average rainfall totals would be expected throughout the decades of ENSO event years, yet no evidence of temporal correlation was found here.

The simulated rainfall distributions produced for the 30 wards are now being used to model maize, small grain, and groundnut yields within the district.

The methodology can be transferred to other situations where point data have a spatial correlation structure and interpolation to contiguous polygons is required.

Biomathematics and Statistics Scotland in developing the FORTRAN program for this paper.

6 REFERENCES

- Brisson, N., B. Seguin, and P. Bertuzzi, Agro-meteorological soil water balance for crop simulation models. *Agricultural and Forest Meteorology* 59 (3-4): 267-287.
- Cane, M.A., G. Eshel, and R.W. Buckland, Forecasting Zimbabwean maize yield using Eastern Equatorial Pacific sea-surface temperature. *Nature* 370 (6486): 204-205, 1994.
- De Jager, J., A.B. Potgieter, and W.J. van den Berg, Framework for forecasting the extent and severity of drought in maize in the Free State province of South Africa. *Agricultural Systems* 57 (3): 351-365.
- Gommes, R., and F. Pettrassi, Rainfall variability and drought in sub-Saharan African since

1960. *FAO Agrometeorology Series Working Paper* 9, 1994
- Gundry S.W., J. Wright, and A. Ferro-Luzzi, Simulating the food and nutrition system in rural Zimbabwe to support targetting of emergency aid'. Proceedings, *ModSim97, the International Congress on Modelling and Simulation*, Hobart, Tasmania, 3: 1018-1022, 8-11 December, 1997.
- Herman, A., V.B. Kumar, P.A. Arkin, and J.V. Kousky, Objectively determined 10 day African rainfall estimates created for Famine Early Warning Systems. *International Journal of Remote Sensing* 18 (10): 2147-2159, 1997.
- Leenhardt, D., Weather generation and climate analysis for crop modelling at a Mediterranean site. Proceedings, *International Symposium Modelling Cropping Systems*, Lleida, Spain: 99-100, 21-23 June, 1999.
- Vaze, P.B., S. Kudhlande, J. Wright, and S. Gundry, A spatial analysis of household grain purchases in Zimbabwe's liberalized marketing system'. *Outlook on Agriculture* 25 (1): 37-42, 1996.

Appendix IX:

Specimen Rule Group 5 for Modelling Framework II

Rulegroup 5: Transfer food crops

Purpose:	To account for storage losses To top up food resources ('larder') to level of 3 dekads requirements	
Rulename	Method	
ComputeStorageLosses	Compute stored foodcrop losses (say ~ 1% per dekad) due to disease, pests etc	
EstimateCurrentRequirements	Estimate kcal requirements for one month from cohort status	
DeductNonStapleKCal	Deduct kcal provided by non-staples (say ~ 10%) from requirements	
ComputeShortfallOfFood	Compute shortfall between requirements and food available in larder	
TransferShortfallStoreToLarder	Transfer shortfall (or amount available, if less) of foodcrops from store to larder	
Dynamic reads:	Table	Field
	tblHouseholdPeople	Infants&& Juniors&& YoungAdultMales&& YoungAdultFemales&& AdultMales&& AdultFemales&& Elderly&&
	tblHouseholdFood	CurrentBalanceKKCal MinimumFoodRequirementsKKCal
	tblHouseholdCash	CurrentBalanceZD
	tblAgEcoZoneStatic	MaizePricePerKgZD
	tblHouseholdCrops	MaizeStorageLossesKg SmallGrainsStorageLossesKg NutsStorageLossesKg MaizeTransferToLarderKg SmallGrainsTransferToLarderKg NutsTransferToLarderKg
Dynamic writes:	Table	Field
	tblHouseholdFood	MinimumFoodRequirementsKKCal MaizeTransferFromStoreKKCal SmallGrainsTransferFromStoreKKCal NutsTransferFromStoreKKCal
	tblHouseholdCrops	MaizeStorageLossesKg SmallGrainsStorageLossesKg NutsStorageLossesKg MaizeTransferToLarderKg SmallGrainsTransferToLarderKg NutsTransferToLarderKg
Temporary variables:	Name	PseudoName
	Var1	StapleFoodAvailableKKCal
	Var2	StapleShortfallKKCal
	Var3	KKCalPerKgMaize
	Var4	KKCalPerKgSmallGrains
	Var5	KKCalPerKgNuts
	Var6	MonthlyRequirementsKKCal
	Var7	MonthlyStapleRequirementsKKCal

ComputeStorageLosses

Compute stored foodcrop losses (say ~ 1% per dekad) due to disease, pests etc

```
MaizeStorageLossesKg=0.01*MaizeCurrentBalanceKg
MaizeCurrentBalanceKg=MaizeCurrentBalanceKg-MaizeStorageLossesKg
SmallGrainsStorageLossesKg=0.01*SmallGrainsCurrentBalanceKg
SmallGrainsCurrentBalanceKg=SmallGrainsCurrentBalanceKg-SmallGrainsStorageLossesKg
NutsStorageLossesKg=0.01*NutsCurrentBalanceKg
NutsCurrentBalanceKg=NutsCurrentBalanceKg-NutsStorageLossesKg
ENDRULE
```

EstimateCurrentRequirements

Estimate kcal requirements for current and next two dekads from cohort status

```
MinimumFoodRequirementsKKCal=
    10*
    (
    1500*(Infants&&+Juniors&&+YoungAdultMales&&+YoungAdultFemales&&)
    2500*(AdultMales&&)
    2200*(AdultFemales&&+Elderly&&)
    )
Var6.MonthlyRequirementsKKCal=3*MinimumFoodRequirementsKKCal
ENDRULE
```

DeductNonStapleKCal

Deduct kcal provided by non-staples (say ~ 10%) from requirements

Var7.MonthlyStapleRequirementsKKCal=0.9*Var6.MonthlyRequirementsKKCal
ENDRULE

ComputeShortfallOfFood

Compute shortfall between requirements and food available in larder

Var1.StapleFoodAvailableKKCal=0.9*CurrentBalanceKKCal

Var2.StapleShortfallKKCal=Var7.MonthlyStapleRequirementsKKCal-Var1.StapleFoodAvailableKKCal

IF Var2.StapleShortfallKKCal
<=0

THEN ENDRULEGROUP

ELSE ENDRULE

TransferShortfallStoreToLarder

Transfer shortfall (or amount available, if less) of foodcrops from store to larder

```

IF      Var2.StapleShortfallKKCal
      <=Var3.KKCalPerKgMaize*MaizeCurrentBalanceKg
THEN
  MaizeTransferFromStoreKKCal=Var2.StapleShortfallKKCal
  MaizeTransferToLarderKg=Var2.StapleShortfallKKCal/Var3.KKCalPerKgMaize
  CurrentBalanceKKCal=CurrentBalanceKKCal+MaizeTransferFromStoreKKCal
  MaizeCurrentBalanceKg=MaizeCurrentBalanceKg-MaizeTransferToLarderKg
  ENDRULE
ELSE
  MaizeTransferFromStoreKKCal=MaizeCurrentBalanceKg/Var3.KKCalPerKgMaize
  MaizeTransferToLarderKg=MaizeCurrentBalanceKg
  CurrentBalanceKKCal=CurrentBalanceKKCal+MaizeTransferFromStoreKKCal
  MaizeCurrentBalanceKg=MaizeCurrentBalanceKg-MaizeTransferToLarderKg
  Var2.StapleShortfallKKCal=Var2.StapleShortfallKKCal-MaizeTransferFromStoreKKCal
IF
  Var2.StapleShortfallKKCal
      <=Var3.KKCalPerKgSmallGrains*SmallGrainsCurrentBalanceKg
THEN
  SmallGrainsTransferFromStoreKKCal=Var2.StapleShortfallKKCal
  SmallGrainsTransferToLarderKg=Var2.StapleShortfallKKCal/Var3.KKCalPerKgSmallGrains
  CurrentBalanceKKCal=CurrentBalanceKKCal+SmallGrainsTransferFromStoreKKCal
  SmallGrainsCurrentBalanceKg=SmallGrainsCurrentBalanceKg-SmallGrainsTransferToLarderKg
  ENDRULE
ELSE
  SmallGrainsTransferFromStoreKKCal=SmallGrainsCurrentBalanceKg/Var3.KKCalPerKgSmallGrains
  SmallGrainsTransferToLarderKg=SmallGrainsCurrentBalanceKg
  CurrentBalanceKKCal=CurrentBalanceKKCal+SmallGrainsTransferFromStoreKKCal
  SmallGrainsCurrentBalanceKg=SmallGrainsCurrentBalanceKg-SmallGrainsTransferToLarderKg
  Var2.StapleShortfallKKCal=Var2.StapleShortfallKKCal-SmallGrainsTransferFromStoreKKCal
IF
  Var2.StapleShortfallKKCal
      <=Var3.KKCalPerKgNuts*NutsCurrentBalanceKg
THEN
  NutsTransferFromStoreKKCal=Var2.StapleShortfallKKCal
  NutsTransferToLarderKg=Var2.StapleShortfallKKCal/Var3.KKCalPerKgNuts
  CurrentBalanceKKCal=CurrentBalanceKKCal+NutsTransferFromStoreKKCal
  NutsCurrentBalanceKg=NutsCurrentBalanceKg-NutsTransferToLarderKg
  ENDRULE
ELSE
  NutsTransferFromStoreKKCal=NutsCurrentBalanceKg/Var3.KKCalPerKgNuts
  NutsTransferToLarderKg=NutsCurrentBalanceKg
  CurrentBalanceKKCal=CurrentBalanceKKCal+NutsTransferFromStoreKKCal
  NutsCurrentBalanceKg=NutsCurrentBalanceKg-NutsTransferToLarderKg
  Var2.StapleShortfallKKCal=Var2.StapleShortfallKKCal-NutsTransferFromStoreKKCal
  ENDRULE
ENDRULE

```